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REPORT OF THE SUPERINTENDENT

OF THE

# UNITED STATES COAST SURVEY,

SHOWING

## THE PROGRESS OF THE SURVEY



DURING

## THE YEAR 1870.



WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1873.

# National Oceanic and Atmospheric Administration

## Annual Report of the Superintendent of the Coast Survey

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# LETTER

FROM

# THE SECRETARY OF THE TREASURY,

TRANSMITTING

## THE REPORT OF THE SUPERINTENDENT U. S. COAST SURVEY FOR 1870.

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MARCH 3, 1871.—Referred to the Committee on Appropriations, and ordered to be printed.

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TREASURY DEPARTMENT,
*February* 18, 1871.

SIR: I have the honor to transmit, for the information of the House of Representatives, a report made to this Department by Professor Benjamin Peirce, Superintendent of the Coast Survey, showing the progress in that work during the year ending November 1, 1870.

Very respectfully, yours,

GEO. S. BOUTWELL,
*Secretary of the Treasury.*

Hon. JAS. G. BLAINE,
*Speaker of the House of Representatives.*

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# REPORT.

COAST SURVEY OFFICE,
*Washington, D. C., February* 7, 1871.

SIR: I have the honor to present, in conformity with law and with the regulations of the Treasury Department, this report, showing the progress made during the year preceding the 1st of November, 1870, in the survey of the Atlantic and Gulf coasts, and of the western coast of the United States.

The season generally was favorable for field-work on both sides of the continent, and the surveying parties being, by custom, ready for service as opportunities offer, the advance has been highly satisfactory in the development of coast features. In proportion to the means, good progress has been made also in the hydrography.

The means provided by Congress at the last session will, at an early day, supply facilities for again pushing the off-shore work. Vessels are under construction to replace the schooners which are not now seaworthy, and two steamers have been contracted for, of size sufficient for hydrographic operations at exposed sites along the coast.

As early as possible in the progress of the survey, the coast was marked off into portions, to be ultimately represented by engraved charts, uniform in scale; the series of sheets being continuous for the Atlantic and Gulf coasts. This could not be done until many points along the sea-board had been determined accurately in position. And, even with the best-defined shore-line, many difficulties would have been met in subdividing so as to give the greatest utility to the intended publications. Of aids to navigation, and sea-marks, the greatest number possible should appear on each of the sheets. This is but one of the desirable conditions. Though we have separate harbor-charts, yet no harbor should be represented in part only on any of our coast-charts. By careful study, however, with regard as well to the limitations just mentioned as to the positions of ports, lights, and headlands, the difficulties have been adjusted as far as possible, and now each of the coast-charts, not already engraved, only awaits the completion of field-work and hydrography within the limits which it is to illustrate. Thus, for several years past, the arrangements for field-work have been in part determined by the condition of the office-work. In some instances, as in regard to the chart of Chesapeake Bay, and others which were issued as early as possible for general uses, parties have since added material, to appear on new editions of the engraved charts.

Each succeeding year brings into view the practical wisdom of the plan upon which the survey was conducted by my predecessor. Under his direction charts of the large seaports were prepared early, to meet the most pressing wants of commerce and navigation. These were to be followed, and have been followed, by the issue in recent years of charts bearing more intimately upon the coast trade. At the same time the off-shore hydrography advanced, continuous observations were made on the tides and on currents, and local surveys were prosecuted when their utility for public purposes was clearly set forth.

It has thus resulted that, while the survey steadily went forward elsewhere, opportunity, as at first intended, has been given for frequently examining the condition of the principal port entrances and harbors. Incidentally, the more important channels have been several times reviewed, and attention has been invited to them occasionally by the municipal authorities. Reports were promptly made by the surveying parties after each examination. The charts of comparison which accompanied these special reports soon enlisted the regard of city authorities for interests that were manifestly liable to injury from artificial encroachment on the water spaces, as well as from natural causes. As a consequence, local laws have been enacted in some cases, and it is hoped that, under their operation, or under some protective law of Congress, our chief harbors may be preserved from injury, as far as the laws of nature will permit.

But the natural forces themselves, which are concerned in the formation and varying conditions of our coast harbors, are within the domain of calculation, and the results from such studies must bear ultimately upon the means adopted for preservation. Moreover, cognate questions of much interest have recently arisen, one of which is in regard to expedients for the reclamation of tide-lands for agricultural purposes. On this I will remark separately. The series of observations on currents and tides now on record in the office, furnish data which have already been employed in the investigations needful for developing the effect of artificial or natural changes in situations subject to tidal action. My personal attention is enlisted in the analytical treatment of the questions which must arise in such investigations.

It will be seen by reference to Appendix No. 1 that the survey in one or other of its branches of work has been prosecuted within the year in all, excepting three, of the sea-board States of the Union. In Part II, short abstracts, arranged for convenient reference, will be given of the reports from the field-parties. A brief statement, mentioning the sites of the operations, accompanied the estimates which were submitted in September last, for continuing the work during the next fiscal year. As all the parties were at that time yet in the field, the synopsis referred to will in general terms be now recapitulated. On the coast of Maine, the harbor of Moose-a-bec Reach has been surveyed and sounded; progress has been made in Southwest Harbor, (Mount Desert Island), in the survey of the Fox Islands, and in soundings at the approaches of Isle au Haut Bay; also in the survey of islands bounding Gilkey's Harbor, (Penobscot Bay), and the western shore of the bay has been mapped between Clam Cove and Ash Point. The banks and channels of the Kennebec have been developed between Richmond and Gardiner; the coast has been surveyed from Old Orchard Beach southward to Cape Porpoise. Stations have been examined in New Hampshire and Vermont, for bringing Lake Champlain into geodetic connection with the survey of the sea-board. On the coast of Massachusetts, the operations include in-shore soundings between Portsmouth, New Hampshire, and the mouth of the Merrimac River, and supplementary work in Plymouth Harbor and Duxbury Harbor; astronomical observations at Cambridge, for determining the longitude of Burlington, Vermont, and the difference of longitude between Cambridge Observatory and Brest, in France, the intermediate station being Duxbury, where observations were also made by telegraphic exchanges with Cambridge and with Brest. Examinations have been made in the vicinity of Marshfield and Scituate, to determine the effect on navigation of expedients proposed for reclaiming tide-lands. On the shores of Narragansett Bay and Saughkonnet River the survey has been actively pushed, and one of the topographical parties has kept the field during the winter near Newport. Tidal observations have been kept up at the established stations of the eastern coast, one in Penobscot Bay, and the other at the Charlestown navy-yard, and a series of observations has been recorded at New Haven, in connection with a review of the triangulation points adjacent.

Progress has been made in the systematic survey of Lake Champlain. Near New York, the positions of all the buoys, lights, and sea-marks concerned in navigation have been determined by angular measurement; and additional soundings have been made on Diamond Reef, off the Battery, on the Oil Spot to the eastward of Sandy Hook, and on Flynn's Knoll, at the entrance to New York Bay. Tidal observations have been continued at Governor's Island. The currents in East River have been further investigated. By lines of level and barometrical observations the heights have been determined of the primary geodetic points between Hudson River and the Delaware, and stations have been selected for connecting Barnegat Light-house with the main triangulation. On the coast of New Jersey the topography has advanced southward from Great Bay to Absecom and Atlantic City. A party is now at work in Delaware River. In Maryland and Virginia, stations have been occupied for the main triangulation south of Washington City, the operations including also observations for latitude and azimuth. The magnetic elements were determined at Washington, District of Columbia, and at Harper's Ferry. Progress has been made in the triangulation of the James River, and the base-line near its entrance is now connected with the triangulation of Chesapeake Bay. Many of the branches of that bay, of local importance, have been surveyed and sounded within the year, as also the Broad Water on the sea-coast of Virginia, north of Cape Charles. Along the sea-board of North Carolina the hydrography has advanced southward to Cape Hatteras. In Pamplico Sound the survey includes the lower part of Pamplico

River; also soundings in Long Bay, and in the vicinity of Brant Island Shoal. The present condition of the western entrance to the Cape Fear River has been developed by soundings for comparison with previous surveys. In view of taking up the plane-table survey, the station-marks along the coast of South Carolina have been examined between Cape Roman and Charleston, and the triangulation southward of that city is now connected with stations on the south side of Savannah River. Plane-table work in that vicinity includes parts of May River and Wright's River, with Bluffton and other districts on the sea islands of South Carolina. On the coast of Georgia the work done embraces the topography of Saint Andrew's Sound and Cumberland Island, with hydrography connecting the two entrances, and also developing the tide-water passages between Cumberland Sound and Saint Andrew's. Saint Augustine Harbor has been sounded, in connection with parts of the Tolomato and Matanzas Rivers. The principal keys in Barnes' Sound and Chatham Bay, near the southern end of the Florida Peninsula, have been mapped within the year, and on the Florida Reef important hydrographic developments have been made in the vicinity of Marquesas.

The survey on the Gulf includes Saint Andrew's Bay, on the western coast of Florida; the hydrography of Lake Borgne, the Rigolets, Lake Saint Catharine, and part of Lake Pontchartrain, on the coast of Mississippi; the shores of Isle au Breton Sound on the coast of Louisiana, and the survey of the banks of the Mississippi River, from Fort Jackson upward to Grand Prairie.

On the coast of California, by extending the main triangulation of the Santa Barbara Channel, that work is now partly connected with the survey of San Francisco Bay, the longitude of the station at Los Angeles having been determined by the telegraphic method. The operations of the year also define the coast features between Point Fermin and Point Vincente, and between Point Gorda and San Buenaventura. Westward of Santa Barbara, the survey now extends to the Goleta. The harbor of San Buenaventura has been sounded, as also the reef in the vicinity of Piedras Blancas. In addition to the continuous tidal observations at San Diego and Fort Point, a series was registered in July and August, from observations on the tidal currents in San Francisco Bay. By angular measurement the positions of buoys for the navigation of San Francisco entrance have been determined. At Punta Arena the operations include the plane-table survey, and observations for latitude, longitude, and the magnetic elements. Humboldt Bay has been sounded; its shores have been mapped, and the coast northward of the entrance as far as Gihon's Bluff. From Crescent City, California, the topography extends northward to Chetko River, on the coast of Oregon. The topographical survey of the shores of the Columbia River is now continuous from the entrance upward to Three Tree Point and Cathlamet Head. Tidal and magnetic observations have been made at Astoria, and magnetic observations at Portland in Oregon. In Washington Territory the work done defines the south shore of the Strait of Fuca from New Dungeness to a point eastward of the entrance to Port Discovery, including Washington Harbor and the shore in the vicinity of Point Wilson; also that of Admiralty Bay on the western side of Whidbey Island; and the surface details of Smith's Island and Minor Island south of the entrance to Rosario Strait. While carrying on the triangulation a dangerous reef was discovered by soundings in that vicinity. East and west of Fort Nisqually, the triangulation has been extended to connect the important astronomical station at Muck Prairie with the survey of Puget Sound.

The operations of the Coast Survey Office, embracing the computation of observations, the drawing, engraving, and publication of maps and charts, have kept pace with the field-work. Eight new charts have been published, and twenty-three others have been advanced by adding the additional results of the previous season's field-work. Eleven new charts have been commenced, and fifty-nine in all have been worked upon. Of the various engraved charts, twelve thousand copies have been printed, and ten thousand four hundred issued. Seventy-two manuscript maps have been copied or traced for various departments of the public service. Tide-tables for the ports of the United States for 1871 have been computed and published, and a new revised and illustrated edition of the Pilot for the Pacific Coast has been issued.

The utility of the results of the survey for general uses, and the confidence which attaches rightly to the product of systematic operations in geographical development, are evidenced in the continued calls for information. Of several classes into which the data now on record in the office might be separated, each has contributed items to meet corresponding requirements. In regard to matter thus given, the Treasury regulation enjoins merely that acknowledgment be made in the publication, if the facts derived from the records of the survey are to be so embodied. The items communicated in the course of the year are recapitulated in Appendix No. 2.

## ESTIMATES.

In explanation of the objects contemplated under the estimates submitted at the end of last September, for continuing work during the fiscal year 1871–'72, I would state that, of the increase proposed for the western coast, twenty-five thousand dollars would provide for the employment of the new steamer now building for the survey of that coast. It would also, in the simplest and readiest manner, provide for the special hydrographic development mentioned in the proviso. The importance of this provision became known to me during an official visit to San Francisco in July, when I learned that unmarked dangers to navigation exist on the sailing route of our steamers between San Diego and Panama. The Chamber of Commerce of San Francisco subsequently took action on the subject, and their urgent memorial in regard to the survey of the route is now in my hands. It is hoped that Congress will sanction an object so important to the safety of our citizens and their property in the line of transit between our eastern and western coasts. The additional fifty thousand dollars of the estimate is intended for the survey of Alaska and the Aleutian Islands, in conformity with the recommendation addressed from the Treasury Department to the House of Representatives at the last session of Congress.

Contracts have been made for the building of several new steamers, for which the means was appropriated at the last session. Hence the item in estimates, for the pay and rations of engineers, has been restored to the amount which was allowed in former years, previous to the decay of the vessels.

The next item is also restored to the original estimate. It is intended to pay for preparing the manuscript records and results for publication. This is a work demanding much labor of a special kind, and it is hoped that adequate provision will be made for that object.

A new item is proposed in the estimates, small in amount, but of inestimable importance to the scientific accomplishment of the survey. As suggested in the proviso which is attached to the estimate for the geodetic connection between the Atlantic and Pacific coasts, a collateral advantage will result, which is also very great in comparison with the sum to be expended. It will give the National Government, and incidentally to the several States of the Union, the best possible basis for all accurate surveys which may hereafter be required. The points determined by the triangulation will be carefully marked to await the future wants of the several States. To some of them the work already done furnishes these invaluable data for their ultimate surveys, and the proviso is inserted in order that the same advantages may be impartially extended to the rest of the Union; first of all to the interior States which lie within the range of triangulation which must join the two coasts; and finally, under the authority of the proviso, it will be extended to all the States equally without limitation.

### ESTIMATES IN DETAIL.

For general expenses of all the sections, namely: Rent, fuel, materials for drawing, engraving, and printing, and for transportation of instruments, maps, and charts, for miscellaneous office expenses, and for the purchase of new instruments, books, maps, and charts, will require ........ $25,000

SECTION I. *Coasts of Maine, New Hampshire, Massachusetts, and Rhode Island.*—FIELD-WORK.—To continue the triangulation of the branches of Passamaquoddy Bay, and to extend the work so as to include the northeastern boundary along the *Saint Croix River*; to continue triangulation for the survey of *Lake Champlain*; to continue the topography of the western shore of *Passamaquoddy Bay*; the estuaries of *Frenchman's Bay*; that of *Southwest Harbor*, and of the islands and shores of *Penobscot Bay*; that of *Saco Bay*; and the topography of the shores of *Lake Champlain*; to continue off-shore soundings along the coast of Maine, and the hydrography of *Frenchman's Bay*, *Goldsborough Bay*, *Southwest Harbor*, *Penobscot Bay*, and *Isle au Haut Bay*; to make soundings in *Lake Champlain*; and to continue tidal and magnetic observations in the section. OFFICE-WORK.—To make the computations from field-observations; to continue the drawing and engraving of General Coast-Chart No. 1, (*Seal Island to Cape Cod*;) to continue the drawing and engraving of Coast-Chart No. 4, (*Naskeag Point to White Head Light, including Penobscot Bay*;) that of No. 6, (*Kennebec entrance to Wood Island Light*;) that of No. 7, (*Seguin Light to Cape Porpoise Light*;) and of Coast-Chart No. 13, (*from Cuttyhunk to Point Judith, including Narragansett Bay*;) to draw and engrave preliminary chart of *Moose-a-bec Reach* and *Southwest Harbor*; to continue the drawing and engraving of the harbor and river charts of the coast of Maine, and the chart of *Narragansett Bay*; and to commence the chart of *Lake Champlain*, will require .................................................. $80,000

SECTION II. *Coasts of Connecticut, New York, New Jersey, Pennsylvania, and part of Delaware.*—FIELD-WORK.—To make supplementary astronomical observations; to continue the triangulation of *Connecticut River*, and complete that of the vicinity of *Barnegat, New Jersey*; to continue the detailed topography of the coast of *New Jersey*, and that of the shores of the *Hudson River*; to execute such supplementary hydrography as may be required in the vicinity of *New York Bay* and *Delaware Bay*; to continue the tidal observations. OFFICE-WORK.—To make the computations and reductions of field-work; to continue the drawing and engraving of Coast-Charts Nos. 21, 22, and 23, (*from Sandy Hook to Cape May*,) will require .......... 15,000

SECTION III. *Coast of part of Delaware, and that of Maryland, and part of Virginia.*—FIELD-WORK.—To continue astronomical and magnetic observations in this section; to continue the primary triangulation parallel to the coast, southward along the *Blue Ridge*; to continue the topography of the sea-coast and bays of *Virginia*, north of *Cape Charles*, that of the shores of the *James River*, and the requisite triangulation; to complete the hydrography of bays and inlets remaining unsurveyed in this section; to continue tidal and magnetic observations. OFFICE-WORK.—To make computations from field-work; to continue the drawing and engraving of Coast-Charts Nos. 29 and 30, (*from Chincoteague Inlet to Cape Henry*;) and of General Coast-Chart No. IV, (*approaches to Delaware and Chesapeake Bays*;) and to continue a chart of the lower part of *James River*, and engrave supplementary work on the charts heretofore published, will require .................................... 38,000

SECTION IV. *Coast of part of Virginia and part of North Carolina.*—FIELD-WORK.—To continue the triangulation of *Pamplico Sound*, and to make the requisite astronomical and magnetic observations; to continue the topography of the western shores of *Pamplico Sound* and complete that of the vicinity of *New River Inlet*; to continue the off-shore hydrography of the section, and that of *Currituck* and *Pamplico Sounds* and their estuaries; and to continue observations on the tides and currents. OFFICE-WORK.—To make computations and reductions; to continue the drawing and engraving of Charts Nos. 42, 43, and 44, (*Pamplico Sound and Estuaries*;) of No. 45 and No. 46, (*coast from Cape Hatteras to Cape Lookout*;) of No. 50, (*Cape Fear River and approaches to Wilmington*,) and of the chart of *Pamplico River*, will require ... 38,000

SECTION V. *Coasts of South Carolina and Georgia.*—FIELD-WORK.—To make the requisite astronomical and magnetic observations on the coast of Georgia; to continue the topography between *Winyah Bay* and *Cape Romain*; to complete the topography and sound the inland water passages between *Charleston Harbor* and *Savannah River*; to continue the off-shore hydrography of the section and tidal observations. OFFICE-WORK.—To make the computations; to continue the drawing and engraving of the General Coast Chart No. VII, (*from Cape Romain to Saint Mary's River*;) of Coast Charts Nos. 56 and 57, (*from Savannah River to Saint Mary's River*;) and of charts of *Altamaha Sound*, *Saint Andrew's Sound*, and the inland tide-water communication on the coast of *Georgia*, will require ................................ 40,000

| | |
|---|---|
| SECTION VI. *Coast, Keys, and Reefs of Florida.*—FIELD-WORK.—To determine the longitude of points on the western coast of *Florida;* to continue the triangulation and topography from *Matanzas Inlet* southward towards *Mosquito Inlet;* to continue the survey of *Tampa Bay;* to complete the hydrography of the *Florida Reef*, and that of the bay of *Florida;* to make explorations in the *Gulf Stream*, and the tidal and magnetic observations. OFFICE-WORK.—To make the computations from field observations; to continue the drawing and engraving of off-shore Chart No. XI, (*western part of Florida Reef, including the Tortugas;*) of Coast Charts No. 75 and No. 76, (*from Caloosa entrance to Tampa entrance,*) and of Coast Charts Nos. 70 and 71, (*Key West to Tortugas,*) will require | $40,000 |
| SECTION VII. *Gulf Coast of the Florida Peninsula, North of Tampa Bay, and Coast of West Florida.*—FIELD-WORK.—To continue the triangulation and topography of *Chattahoochee Bay*, and of the *Gulf Coast* eastward and westward from it, and to make such astronomical and magnetic observations as may be requisite in the section; to survey and sound the entrance to the *Suwanee River;* to complete the hydrography of *Saint George's Sound*, and to continue the tidal observations. OFFICE-WORK.—To make the computations from field-work; to continue the drawing and engraving of Coast Charts No. 82 and No. 83, (*from Ocilla River to Cape San Blas,*) and of General Coast Chart No. XIII, (*Cape San Blas to Mobile entrance,*) will require | 30,000 |
| SECTION VIII. *Coasts of Alabama, Mississippi, and part of Louisiana.*—FIELD-WORK.—To extend the triangulation westward from the *Mississippi Delta*, along the *Gulf Coast*, and to make the astronomical and magnetic observations required in this section; to commence triangulation for the survey of the *Mississippi River* and its principal tributaries in the vicinity of *Saint Louis, Cincinnati*, and such other points as may be practicable; to continue the survey of the *Mississippi*, between the heads of the Passes and *New Orleans*, and make soundings within the same limits; to complete the hydrography of *Lake Pontchartrain*, and complete unfinished work to the northward of *Isle au Breton Sound*, and to make the tidal observations. OFFICE-WORK.—To make the computations pertaining to field-work; to continue the drawing and engraving of the General Chart No. XIV, (*Gulf Coast between Mobile Point and Vermilion Bay,*) and of Coast Chart No. 91, (*Lake Borgne and Lake Pontchartrain,*) No. 92 and No. 93, (*Chandeleur Islands to Southwest Pass,*) will require. | 50,000 |
| SECTION IX. *Coast of part of Louisiana and Coast of Texas.*—FIELD-WORK.—To measure a base-line for verification; to continue the triangulation and topography of *Madre Lagoon*, from *Corpus Christi Bay* southward; to complete the hydrography of *San Antonio* and *Espiritu Santo Bays;* to continue the off-shore hydrography, and to make the requisite tidal observations. OFFICE-WORK.—To make the office computations; to continue the drawing and engraving of Coast Charts No. 108 and No. 109, (*Gulf Coast from Matagorda to Corpus Christi Bay,*) and to continue the drawing and engraving of General Chart No. XVI, (*Gulf Coast from Galveston to the Rio Grande,*) will require | 35,000 |
| Total for the Atlantic Coast and Gulf of Mexico | 391,000 |

The estimate for the Pacific Coast of the United States is intended to provide for the following progress in the survey:

SECTION X. *Coast of California.*—FIELD-WORK.—To make the required observations for latitude, longitude, and azimuth, at stations on the coast; to make magnetic observations; to connect the *Santa Barbara Islands* with the coast triangulation, and continue the coast topography northward from *Point Conception;* to continue the off-shore hydrography of the coast of *California*, and to make such local surveys along the coast as the progress of development may require; to continue the tidal observations. OFFICE-WORK.—To compute results from observations, and continue the drawing and engraving of maps and charts made in the field; also for operations in—

SECTION XI. *Coasts of Oregon and Washington Territory.*—FIELD-WORK.—To continue the astronomical and magnetic observations in this section, and the triangulation, topography, and hydrography in *Washington Sound* and in *Puget Sound;* to continue the survey of the *Columbia River*, and to make such local surveys as may be called for by public interests on the coast of *Oregon* or on the waters of *Washington Territory*. OFFICE-WORK.—To continue the drawing and engraving required by the field-work, and for operations in—

SECTION XII. *Coast of Alaska.*—To develop as far as practicable the hydrography of the coast and that of the vicinity of the *Aleutian Islands*, and for the record of such observations as may be made in a general examination of the coast features, will require .......... $275, 000

For extending the triangulation of the Coast Survey so as to form a geodetic connection between the Atlantic and Pacific coasts of the United States, including compensation of civilians engaged in the work .......... 15, 000

For pay and rations of engineers for the steamers used in the Coast Survey, no longer supplied by the Navy Department .......... 10, 000

For continuing the publication of the observations made in the progress of the Coast Survey, including compensation of civilians engaged in the work, the publication to be made at the Government Printing Office .......... 10, 000

For repairs and maintenance of the complement of vessels used in the Coast Survey..... 45, 000

The annexed table shows, in parallel columns, the appropriations made for the fiscal year 1870–'71, and the estimates now submitted for the fiscal year 1871–'72:

| Object. | Estimate for fiscal year 1871–'72. | Appropriated for fiscal year 1870–'71. |
|---|---|---|
| For continuing the survey of the Atlantic and Gulf coasts of the United States and Lake Champlain, including compensation of civilians engaged in the work, and excluding pay and emoluments of officers of the Army and Navy, and petty officers and men of the Navy, employed in the work, per act of March 3, 1843 | $391, 000 | $391, 000 |
| For continuing the survey of the western coast of the United States, including compensation of civilians engaged in the work, per act of September 30, 1850: *Provided*, That the operations shall include a hydrographic development of the dangers to ocean navigation between San Diego and Panama | 275, 000 | 200, 000 |
| For extending the triangulation of the Coast Survey, so as to form a geodetic connection between the Atlantic and Pacific coasts of the United States, including compensation of civilians engaged in the work, per act of March 3, 1843: *Provided*, That the triangulation shall determine points in each State of the Union which shall make requisite provision for its own topographical and geological surveys | 15, 000 | |
| For pay and rations of engineers for the steamers used in the Coast Survey, no longer supplied by the Navy Department, per act of June 12, 1858 | 10, 000 | 5, 000 |
| For continuing the publication of the observations made in the progress of the Coast Survey, including compensation of civilians engaged in the work, per act of March 3, 1843, the publication to be made at the Government Printing Office | 10, 000 | 2, 000 |
| For repairs and maintenance of the complement of vessels used in the Coast Survey, per act of March 2, 1853 | 45, 000 | 45, 000 |
| Total | 746, 000 | 643, 000 |

## GEODESY.

The problem of finding the geometrical expression for a surface most nearly in accord with the results of astronomical and other observations, made in the progress of the primary triangulation, has been as far advanced by Assistants Hilgard and Schott as the present state of the field-work will admit. They have also indicated the field observations yet needed for the solution of the problem. A preliminary discussion has been made involving a large number of conditional equations between latitudes, longitudes, and azimuths determined on the coast of New England and in the Middle States. An arc is thus intercepted of about nine and a half degrees; the triangulation is yet regarded as developed on the surface of Bessel's ellipsoid, but the computation of the geodetic latitudes, longitudes, and azimuths, as now intended, will apply ultimately to a surface deduced from the whole series of measurements, making the sum of the squares of discrepancies between the geodetic and the astronomical measures a minimum. To the analysis of this problem in its generality my own personal attention will be given.

## THE RECLAMATION OF TIDE-LANDS.

The reclamation of tide-lands for agricultural and commercial purposes having of late become an object in the investment of capital, Assistant Henry Mitchell, in charge of the Physical Hydrography, was directed to investigate the various schemes presented, with a view to ascertain in what measure enterprises of this kind are likely to effect navigable channels. The office is frequently called upon to furnish information derived from our surveys, and the opportunity is thus afforded for encouraging the utilization of waste marsh-lands, and at the same time advising the communities which undertake these works against injurious encroachments upon their valuable water-ways. The problems offered in the reclamation of land are the reciprocals of those which have been studied relative to the preservation of channels, and they pertain naturally to the domain of our physical surveys. I have, therefore, instructed Assistant Mitchell to meet, as heretofore, calls for information, and at the same time to report the nature of the projects proposed, and their bearing upon matters of navigation. Among his reports of the past season, one upon this special subject is given in the Appendix No. 5 of the Report for 1869. The importance of the matter is well stated in the opening remarks in that paper, which cite the results of experience in Europe to show how frequently reclamations, improperly planned and executed, have caused injury to navigation, even at a considerable distance from the actual ground of operations. Mr. Mitchell's discussion of the origin of the marshes and the wear of the outside coasts, as inviting to further study, is deserving of special attention. He concludes that the waves of the sea, in washing down the headlands, assort the materials; that the stones go to build the shingle-levees and the coarse sands to the extension of beaches, while the finer material is driven into sheltered coves and that it ultimately forms the marshes. Evidence from surveys and from many reliable observations certainly warrant the belief that the great gulfs and bays open in the direction from which storm-winds commonly blow, are extending into the continent, while all sheltered harbors and coves are filling up.

As a general rule of easy application for deciding upon the practicability of lowering the water-level of a river by constructing a transverse sluice-dam, I have proposed the following, and at my request it is discussed in the report of Assistant Mitchell, namely: *Draw a tangent to the tidal curve at the point where the tidal current changes from ebb to flood; if this tangent intersects the descending branch, the reclamation will preserve from overflow all the land that is higher than the point of intersection.*

Under Section I, mention will be made of the local examinations of the present season to which the principles thus far developed are applicable.

## OBITUARIES.

Assistant Edward Cordell, of the Coast Survey, one of the most accomplished of hydrographic officers, died suddenly, in the prime of manhood, at San Francisco, on the 25th of January. In the record of this sad event, it is fitting to make mention of the qualities thus lost to the service. For some years previous to his period of duty afloat, Mr. Cordell was known and recognized as a hydrographic draughtsman unsurpassed either in skill or in the finish of his charts. There was at the same time, latent under an unobtrusive disposition, the ability to master any difficulty presented in the branch of service which it had been his part to illustrate. In 1862 he took charge of a hydrographic party, and at once brought into practical use the observations and experience quietly treasured while associated in a less active capacity with sounding parties. The large hydrographic results of the three following years on the Atlantic and Gulf coasts were evidence that the veracity and finish of his charts rested on a complete mastery of all the principles involved, and a special readiness in their application. Ardent in service and unrivalled in the profession, he was, in 1865, placed in charge of the hydrography of the western coast, and there evinced special fertility in applying expedients for the prosecution of difficult work. His calm temperament and unvarying courtesy to his aids and men had ample returns in their cheerful compliance with the requirements for the service, incident to his own energy.

In Assistant Cordell were joined great executive ability, system, and consecutiveness in action, and the spirit to incur any reasonable risk or personal discomfort in the performance of duty. In every relation his loss is deplored by his associates. His name and his memory are still left to honor our roll of hydrographic officers.

Assistant John G. Oltmanns, after a protracted illness, died at Hollywood, on Mobile Bay, on the 2d of September, and, as he had previously requested, was wrapped in a flag of the Union for interment. In the assimilated rank of major, he had realized throughout the war the collateral advantage that may inure in military service, from previous experience in peaceful field-operations. Mr. Oltmanns joined the Coast Survey in 1852. As a civilian he worked subsequently in widely separated sites on the coast of the Gulf States, alternately in triangulation and as a topographer. The unflinching resolution which stayed up a constitution, not robust, under hardships and risk of health in the civil service, accompanied him in the performance of adjunct duties with the fleet and armies that operated in the Valley of the Mississippi. Reference has been made in previous annual reports to the activity and constancy of Mr. Oltmanns in thus sustaining relations which enhanced his responsibilities. Consumption had undermined his strength, and the crisis of disease was hastened in consequence of a severe wound, caused by the passage of a rebel rifle-ball quite through his lungs. This occurred in May, 1862. He rallied from that critical injury and continued in service on the Mississippi and in Louisiana. Though his life was several times in great peril in that quarter, he returned to the office when hostile movements ceased, and went through the subsequent campaign in the Shenandoah Valley. In that, as in others, he accompanied the staff, and contributed to the service the results of his aptitude in reconnaissance and in sketching maps. With characteristic energy he resumed field-work in the survey of the Gulf coast at the close of the war, and completed labors that could be undertaken only by one inured to the hardships and discomforts of a camp at sea-level. The last survey by this amiable and highly-esteemed officer was finished only a few weeks before his death.

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# PART II.

The distribution of the surveying-parties on the coast of the Atlantic and Gulf, and on the western coast of the United States, is exhibited in tabular form in Appendix No. 1. Corresponding in general order to the list of names and places there given, the notices in this part of the report will include ordinary particulars; the mention, as heretofore, being confined to the essential facts pertaining to each of the surveys; hence the notices will regard such details only as are most likely to be sought for in future reference. The usual order will be observed, Section I beginning at the northeastern boundary of the United States, on the Saint Croix River, in Maine; and Section IX terminating on the Gulf at the Rio Grande, on the coast of Texas. From San Diego northward, Sections X and XI include the Pacific coast of the United States, to the mouth of Frazer River, in Washington Territory.

In the course of the year, the triangulation and reconnaissance for its extension have been continued where required for the regular progress of the survey and, in exceptional cases, for the publication, in advance, of charts called for by the immediate necessities of commerce. On the Atlantic and Gulf coast, the details of the triangulation in relation to the branches of work depending upon it have been further systematized by the special attention of Assistant Richard D. Cutts. To his large experience and his readiness in field-operations is due the conviction that any emergency likely to arise in the progress of the survey can be promptly met. Mention will be made under proper heads of the field-work in which he was personally engaged; in addition to which he visited and conferred with several of the chiefs of parties in their sites of work.

On the eastern coast of the United States twelve parties have been employed, at eighteen different localites, in triangulation or in collateral duties. Two bases of verification have been measured, one on the Gulf coast of Florida, and the other on the coast of North Carolina. A preliminary base was also measured, under the direction of Assistant Cutts, near the shore of Lake Champlain.

In Section II, the routine of operations was varied during two months of the working-season, in order to meet the direction contained in the act of Congress, entitled "An act making appropriations for sundry civil expenses of the Government, for the year ending June 30, 1870," approved July 15—that the means therein provided for continuing the survey of the Atlantic and Gulf coast should be applied, in part, for a survey of Lake Champlain. The system and methods used in the survey of the coast were, in consequence, with a suitable force, transferred to the lake, and the survey was advanced as far as the limited season and the collateral interests of work on the coast would allow. The progress made in the survey of Lake Champlain will be described under the head of Section II. On a review of the facts which give it special importance, the provision by which it has been included in surveying-operations seems to be fully warranted.

This narrow lake, about one hundred miles in length, and entirely within the limits of the United States, is connected with Hudson River by the Champlain Canal, and with the Saint Lawrence by its natural outlet, the Richelieu River, the navigation along the latter being improved by the Chambley Canal. Thus there is an almost direct line of water-communication between New York City and Montreal. Further improvements now in progress, and others which are proposed, will shorten this line, and realize, it is expected, all the advantages for domestic intercommunication to be derived from the position, direction, and extent of Lake Champlain, as a natural link between the great lakes and the Atlantic Ocean. It is intended to make the new canal, to connect the navigable waters of the lake with the Saint Lawrence above Montreal, of capacity sufficient to pass vessels of 850 tons. Lake Champlain, when this is accomplished, will be one of the principal routes of trade and commerce between the Northwestern and the Eastern States of the Union.

Besides the aid to commerce which will be afforded by a thorough survey and development of the channels of the lake and of the dangers to its navigation, the connection of the survey with the geodetic work already done on the coast will incidentally supply data of value for the improvement of the post-route maps, and for the extension, previous to measurement, of the arc of the meridian which passes through the valley of the Hudson. To this arc further allusion will be made in its proper place.

In April last the Committee on the Post-Offices and Post-Roads, of the House of Representatives, referred to my attention suggestions made by the topographer of the Post-Office Department, with a view to improve as far as limited means would allow the imperfect state of maps which of necessity are yet used in contracts for mail-service.

The needs thus brought to view in regard to facilities for public uses, are obvious. Provision might in time be made for them by the adoption of the plan for triangulation across the States included in the estimates for the coming fiscal year; and if the exigencies of the postal service permit the delay, the method therein proposed would suffice. The subject presented by the committee was, however, regarded as of high importance in itself, but, in so treating it, the ulterior advantages that might be derived from any outlay for that specific object were kept in view. I therefore approve the remark, in the report by Assistant Cutts, which was transmitted early in May, as a response to the request of the committee, that "in the mean time every extensive survey undertaken by national or State authority, should be executed, as far as possible, with a view to ultimate connection with the net-work of triangulation, starting from the coast and extending over the principal valleys of the interior, so that each survey made may be placed hereafter in its proper relative position."

Besides the immediate uses contemplated, the work submitted to the consideration of the Committee on the Post-Offices and Post-Roads would be valuable in other respects, as suggested in my remarks which accompanied the estimates for the next fiscal year.

The expression of my thanks is due to Assistant Cutts for the special care, and for the systematic precision which mark his treatment of all questions pertaining to the branch of service under his charge.

The general care in regard to topographical details has been continued with Assistant H. L. Whiting. Most of the plane-table parties were visited while at work in the field, with reference, as heretofore, to maintaining uniformity in the style of representation. The party operations connected with the topographical survey of Lake Champlain were arranged by Mr. Whiting.

No delay has been permitted in applying the means, appropriated by Congress, for new vessels to replace those which have been worn out in service by the topographical and hydrographic parties. The special care of the hydrographic inspector, Captain C. P. Patterson, was, at the earliest moment, given to details in regard to draught, size, and such other particulars in the construction of the vessels as would give the utmost efficiency for the outlay. Contracts were made as soon as possible, and, in the interests of the service, unremitting attention has been given to insure complete satisfaction in the delivery of the vessels. It is expected that two of the schooners and a small steamer will be ready for service early in the coming spring. The hydrographic division, meanwhile, has been maintained in its accustomed relation to the other branches of the office. Original charts as they arrive are examined with reference to standard requirements, and selections are made from the soundings, so that the engraved charts may be characteristic of the coast-approaches which they are to represent. The routine of the division in other respects has been kept up as heretofore, and my thanks are due for the great advantage which accrues to the service from the ability and experience of Captain Patterson.

On the western coast, the season was in general favorable for work, and the statistics indicate that every opportunity was taken to make advances in results. Assistant George Davidson, in addition to the operations conducted by himself personally, inspected most of the other sites of operations in the course of the year and indicated the limits of the field-parties. It was a source of gratification to find in July, when I visited San Francisco, that all the plans approved in the preceding winter were going forward in accordance with the respective allotments. Of the large results brought in at the close of the working season, separate notices will be made under the heads of Sections X and XI. In passing to and fro from San Francisco, as far to the southward as San Pedro, on the Santa Barbara channel, and as far northward as Puget Sound, Mr. Davidson gave attention, as heretofore, to the development of the different branches of work on the Pacific coast, and to questions of collateral importance. The results of his experience and observations on the fogs, in relation to the best aids for navigation, have been communicated to the Light-house Board, as also his views in regard to the location of light-houses and buoys. He has met the numerous calls at San Francisco, and elsewhere on the Pacific coast, for information such as can be derived only from final surveys. These applications are comprised with others of like character in Appendix No. II.

Assistant Davidson has also much advanced the compilation of the second part of his Coast-Pilot for Alaska, and the publication may be expected at an early day.

A buoy has been placed on the Presidio Shoal in San Francisco Bay; and a mammoth buoy at the western edge of the Boneta Channel, in accordance with the recommendation of Mr. Davidson. The untiring zeal with which he has pressed forward the field-work upon the western coast, and the constancy of his communications in regard to its progress, deserve my special acknowledgment.

## SECTION I.

### ATLANTIC COAST OF MAINE, NEW HAMPSHIRE, MASSACHUSETTS, AND RHODE ISLAND, INCLUDING SEA-PORTS, BAYS, AND RIVERS. (SKETCH No. 2.)

*Topography of Moose-a-bec Reach, Maine.*—In order to the early issue of a chart of the harbor afforded by Moose-a-bec Reach, the shore-line survey was taken up in July by the party of Assistant J. W. Donn. During August the field-work, on this part of the coast of Maine was hindered by fogs, but the remainder of the season being favorable, the topography of the shores and of the adjacent islands was mapped by the middle of September. As far as practicable the plane-table work was made to include such of the neighboring ledges as are visible at low water.

This party had passed the early part of the year in Section III. Assistant Donn was efficiently aided in both sections by Mr. L. B. Wright. A summary of the plane-table statistics of work at Moose-a-bec Reach is appended:

| | |
|---|---|
| Shore-line surveyed | 132 miles. |
| Roads | 24 miles. |
| Area of topography, (square miles) | 18 |

Eighty-six islands are represented in contour on the topographical sheets.

Assistant Donn is now at work with his party on the sea-coast of Virginia.

*Hydrography of Moose-a-bec Reach, Maine.*—The soundings were made by Assistant F. F. Nes, with a party, in the schooner Joseph Henry and steam-launch Sagadahoc. Signal swere set up in the latter part of July. From time to time tracings of the shore-line were furnished by Assistant Donn, and the vicinity represented by each was filled with soundings as the weather favored, work afloat being sometimes practicable in the western entrance, when it was not so in the eastern part of the Reach.

The hydrography includes Nash Island light-house to the westward; and to seaward Flat Island and Crumple Island; also the adjacent waters; Indian River, Chandler's Bay, West River, and numerous coves. Many ledges were patiently developed by soundings, but some yet remain to be examined in order to complete the curve of depth at three fathoms. One hundred and five signals were used for hydrographic purposes. Of these sixty were erected by the party of Assistant Nes. Messrs. W. I. Vinal and R. B. Palfrey served as aids.

Tidal observations were made and recorded as usual while soundings were in progress. The general statistics of the work are as follows:

| | |
|---|---|
| Miles run in sounding | 891 |
| Angles to determine positions | 4,300 |
| Number of soundings | 38,272 |

The buoys and spindles, twenty-four in number within the working limits, were determined in position and marked on the hydrographic sheets.

The vessels used in this survey sailed from Jonesport on the 27th of October, and were laid up for the winter at Portland. Assistant Nes with his aids soon after took up duty in Section IV, where the party had been employed in the preceding winter and spring. Records of the soundings and angles in the survey of Moose-a-bec Reach, contained in nineteen volumes, have been placed in the office.

*Triangulation of Southwest Harbor, Mount Desert Island, Maine.*—Soon after the return of Assistant G. A. Fairfield from Section IV, he was assigned to duty, with instructions to extend the triangulation over Southwest Harbor and Somes's Sound, Mount Desert Island, Sketch No. 2, starting from the nearest well-determined line of the work already done. This triangulation is to serve as a basis for the topographical and hydrographic survey which will follow. A harbor-chart, now much needed on that particular part of the coast of Maine, will thus be completed in time for insertion in this report, Sketch No. 18. Assistant Fairfield was also directed to determine, by trigonometrical leveling, the height, above mean tide, of Green Mountain and of other prominent elevations on the island, in the vicinity of his field of labor.

Between the 23d and 29th of July, a reconnaissance was made, and at the latter date the triangulation was commenced and continued systematically until the 19th of September, when the operations were completed.

As a basis for the leveling, a mark was made at low water, on a pile of the steamboat-wharf in Southwest Harbor, and a bench-mark was established on the wharf. The difference of elevation between these two was determined by the spirit-level, and also the difference of height between the bench-mark and the telescope at the station "Church Spire," (Southwest Harbor,) at which the vertical angles were commenced.

The statistics of the work are as follows:

| | |
|---|---|
| Signals erected | 11 |
| Points determined | 20 |
| Stations occupied | 8 |

| | |
|---|---|
| Angles measured | 82 |
| Single observations | 1,024 |
| Vertical angles measured | 6 |
| Number of observations | 260 |

Assistant Fairfield has now resumed field-duty in Section IV. Mr. W. B. Fairfield served as temporary aid in that section, and also in the party on the coast of Maine.

*Hydrography of Penobscot Bay, Maine.*—The work of Assistant F. P. Webber, between the 20th of July and the end of October, extended the hydrography of the seaward approaches of Penobscot Bay to the eastward, quite across the entrance and including the southern approaches to Isle au Haut Bay. Soundings were resumed at the limit previously reached in the vicinity of Brimstone Island and Seal Rock, and the lines showing depth were continued eastward beyond Great Spoon Island.

Early in September, Assistant Webber took up the hydrography south and east of the Fox Islands in Penobscot Bay, and completed soundings between Heron Neck Light and Calderwood's Point, including the islands and ledges of that vicinity. This work joins with a hydrographic sheet of Isle au Haut Bay, made last year by Assistant Junken. Many sunken ledges are developed on the sheet of the present season. Shore-line and the points needed for soundings were furnished by Assistant Dorr and Sub-Assistant De Wees.

Sub-Assistant F. D. Granger, who rendered effective service in the hydrographic operations, was detached when the working season closed at the north, and is now conducting a party in Section IX.

The steamer Endeavor was used by the hydrographic party on the coast of Maine. Mr. Andrew Braid aided in the soundings. The following is a synopsis of the statistics of work:

| | |
|---|---|
| Miles run in sounding | 1,039 |
| Angles measured | 11,035 |
| Number of soundings | 31,981 |

The weather of the present season was unusually good, and the progress of the parties afloat was but little interrupted by fog.

Assistant Webber is now engaged in hydrographic duty in Section V. His service previous to taking up work on the coast of Maine will be referred to under the head of Section VIII.

*Topography of the Fox Islands, (Penobscot Bay,) Maine.*—Plane-table work has been extended over the southeastern part of the Fox Island group, by the party of Assistant F. W. Dorr. No vessel being available for use in the topography, Assistant Webber, while on his way in the steamer Endeavor to prosecute the hydrography of the vicinity, took in the camp and instruments of Mr. Dorr, at the mouth of George's River, and landed them at Carver's Harbor. By the close of July arrangements were complete for work in the field. Incessant fogs until the middle of August retarded the progress, but in the latter part of that month Carver's Harbor was surveyed, including the village and several of the outlying islands and ledges, as well as part of the interior of the principal of the Fox islands.

Early in September, Mr. Dorr, under instructions, left the party in charge of Sub-Assistant H. M. De Wees, who had accompanied him to the field, and took part in the survey of Lake Champlain, details in regard to which will be given in this report under the head of Section II.

Mr. De Wees continued work with the plane-table in Penobscot Bay until the 1st of November, but unfavorable weather made it impracticable to complete the details falling within the limits of the projected sheet. Amongst these are comprised numerous ledges and small islands, the outlines of which, for chart purposes, could be traced only at low water. The work is, however, laid out systematically as far up as Seal Bay, and can be completed in the course of a few weeks of favorable weather in the next working season. The progress made this year is shown in the following statistics:

| | |
|---|---|
| Shore-line surveyed | 50 miles. |
| Roads | 37 miles. |
| Area of topography, (square miles) | 16¼ |

Mr. Dion Bradbury, jr., who was attached as aid to the plane-table party, accompanied Assistant Dorr to the site of work in Section II. Mr. De Wees is now at work in Section VII.

*Topography of Islesborough in Penobscot Bay.*—For extending the plane-table survey upward in Penobscot Bay, two sheets were projected and sent to Assistant A. W. Longfellow in July. His party left Portland in the schooner Meredith, and before the close of the month commenced the survey. Field-work was continued until the 25th of October. The details returned on the topographical sheets comprise the small islands and rocks south of Islesborough in Penobscot Bay, the largest being Seven Hundred Acre Island. Part of Long Island was also surveyed, and the lesser ones known as Warren's, Lasell's, and others which as a chain divide the water-space of the bay above Camden. These outlying islands are craggy and wooded, and being accessible only in favorable weather, the party encountered considerable difficulty in their delineation. The work, however, was advanced to some distance above the south end of Islesborough, and can be conducted with greater facility in the extension of the survey northward.

Mr. C. B. Fuller was attached to the party as temporary aid. The results of the season are thus stated in the field report:

| | |
|---|---|
| Shore line surveyed | 40½ miles. |
| Roads | 3 miles. |
| Area contoured, (square miles) | 3½ |

Special determinations were made at low water, in order to define the bars and ledges which are covered at other stages of the tide.

*Topography of Rockland Harbor, Maine.*—The detailed survey of the vicinity of Rockland was commenced on the 11th of July, by Assistant W. H. Dennis, and was completed on the 18th of November. On the south side this work joins near Ash Point with the plane-table sheet showing South Thomaston and its vicinity. The topography mapped represents a fringe averaging a mile and a half in width from the shore-line of Penobscot Bay, and extending northward to a point about half a mile above Clam Cove, where Mr. Dennis joined his work with a survey previously made by Assistant Dorr. Within the limits described are included the city of Rockland, and a large amount of such details as require the utmost care of the topographer.

After completing the sheet, Assistant Dennis mapped a small area for connecting the topography of George's River with that of Tennant's Harbor. His results are shown on Sketch No. 15. His operations in this section are represented in the following summary:

| | |
|---|---|
| Shore-line surveyed | 27 miles. |
| Roads | 60 miles. |
| Area of topography, (square miles) | 21 |

Mr. G. W. Bissell was attached to the party as aid. Assistant Dennis has now resumed work in Section V, under which head his occupation of last winter and spring will be mentioned in a subsequent part of this report.

*Topography and hydrography of the Kennebec River, Maine.*—Field-work was resumed in the Kennebec by Assistant C. H. Boyd on the 25th of July at Richmond, (Sketch No. 15,) the topography of last year having included Swan Island. In its course upward the plane-table work of the present season shows both banks of the river as far as Gardiner, in varied detail, some a mile but others only a half a mile from the shore-line of the Kennebec. The hydrography of the river was completed within the same limits, and a series of tidal observations was recorded, as usual, while the soundings were in progress. In order to take in Eastern River, Mr. Boyd made a triangulation of its course and included it in his topographical and hydrographic survey. He also ran a line of levels, in the aggregate twenty-seven miles, to connect with the tidal-station established in 1861 on Merry-Meeting Bay, the stations at which observations had been subsequently made by officers of the United States Engineers, or by himself at Gardiner, Hallowell, and Augusta. The tidal observations made below Gardiner are on record in the Coast Survey Office.

The report of Assistant Boyd describes the river obstructions that exist between Richmond and Gardiner. These are all within the reach of ordinary engineering expedients, and will, doubtless, soon be removed.

The statistics of plane-table and hydrographic work are as follows:

| | |
|---|---|
| Shore-line traced | 36½ miles. |
| Roads | 52 miles. |
| Area of topography, (square miles) | 17 |
| Miles run in sounding | 84 |
| Angles measured | 1,604 |
| Casts of the lead | 11,830 |

The currents of the Kennebec were observed in the usual way and will be indicated on the published chart.

Assistant Boyd closed this work early in November and returned to Section VIII, where he had been previously engaged. His aid, Mr. J. N. McClintock, was then transferred to duty in Section V.

*Topography near Cape Porpoise, Maine.*—The party of Assistant Hull Adams took the field on the 5th of July at Kennebunkport, and continued northward with the detailed plane-table survey of the coast of Maine, closing for the season on the 1st of November. His work includes the coast-line and rocky islands between Cape Porpoise and the mouth of Saco River, about a mile of the lower course of that river, and the coast features in the vicinity of Old Orchard Beach beyond it. The intervening marshes were mapped, and the ground on both sides of the road which passes along the coast from Kennebunkport to Saco. Several small harbors were developed in outline, among them that near Cape Porpoise, which, during easterly storms, is resorted to as a harbor of refuge; it sometimes contains a hundred or more schooners, pressed in from sea by the weather. North of the harbor the topographical sheet shows the course of Little River, Hoyt's Neck, Saco Beach, and Biddeford Pool, the last being a place of summer resort, to which several steamers run from Saco. The Pool serves as a harbor for small fishing-vessels; beyond it Assistant Adams and his party surveyed Fletcher's Neck and the ledges and islands in that vicinity. The general statistics of work are given in the following summary:

| | |
|---|---|
| Shore-line surveyed | 38 miles. |
| Rivers, creeks, and islands | 32 miles. |
| Marsh-line | 34 miles. |
| Roads | 42 miles. |
| Area of topography (square miles) | 27½ |

Mr. Eugene Ellicott joined the party, as aid, on the 18th of July, and continued in the field until September, when he became seriously ill. Mr. Adams was aided during the latter part of the season by Mr. O. H. Tittmann.

Assistant Adams is now conducting a plane-table party in Section IV.

*Reconnaissance.*—Parties having been detailed in August for the survey of Lake Champlain, Assistant G. W. Dean was at the same time directed to note, on the intervening ground, the feasibility of connecting stations near the lake with the nearest stations of the primary triangulation of the coast of New England. Mount Washington, although not occupied with the theodolite, was marked and observed upon in 1849 from one of the coast stations near Portland, and subsequently from three others. Mr. Dean identified the marks at that station, and then visited Mount Mansfield, in Vermont, where, however, owing to smoke in the atmosphere, the shores of Lake Champlain were not visible. The reconnaissance was continued in the vicinity of Saint Albans, and thence, down the lake, by the way of Burlington, to Caldwell. At a suitable elevation there the observer finds in view the Green Mountains to the eastward and the Adirondacks to the westward. Passing by the way of South Adams, Mr. Dean reached Greylock Mount, the highest point in Massachusetts, on the 1st of September. From that summit three of the principal stations which have been occupied in the survey of the coast are visible in clear weather. Other duties pressing at the time, the reconnaissance was extended no further. In order to complete the examination, Gunstock Mount in New Hampshire is yet to be visited, and the practicability ascertained in regard to its connection with Ascutney in the town of West Windsor and Mount Mansfield in Vermont. An early opportunity will be taken to decide on the most direct means of bringing the survey of Lake Champlain into connection with the work on the coast. The progress made by the parties assigned for the detailed survey of the lake will be stated under the head of Section II.

*Hydrography between Portsmouth, New Hampshire, and Merrimac Entrance, Massachusetts.*—With a vessel chartered for this work, Sub-Assistant Horace Anderson took up the service early in August, using also boats which had been lent by the Commandant of the Charlestown Navy-yard. The in-shore hydrography was prosecuted until the 24th of September, the party, at that date, having completed soundings along the coast of New Hampshire and Massachusetts, between the entrance to Portsmouth Harbor and the mouth of the Merrimac River. Many ledges were developed, the coast approaches being lined with them between Hampton River and Portsmouth Harbor. The rocks existing here are from half a mile to a mile off shore; some are sunken and others stand three or four feet out of water. Hampton River entrance was sounded by Mr. Anderson, and the depth on the bar was found to be only four feet at mean low water. The channel inside, moreover, is narrow and intricate. Tidal observations were recorded by the party at this entrance and also at Rye Harbor, for the adjustment of depths, the soundings being made under favorable circumstances at all stages of the tide.

Messrs. F. W. Ring and W. H. Stearns served as aids in the hydrographic party. The chart resulting from the work has been received at the office.

*Longitude.*—Mention will be made under Section II of the determination of longitude at Burlington, Vermont. The results were obtained by our established method, telegraphic signals being exchanged at instants of time, well ascertained by the observation of particular stars. As usual, the free use of their line was afforded by the Western Union Telegraph Company. Professor Joseph Winlock, director of the Cambridge Observatory, exchanged star-signals with Assistant G. W. Dean, on the nights of the 26th and 28th of September, and on the night of the 2d of October, one observer being at Cambridge and the other at Burlington. The co-operation of Professor Winlock in similar determinations will be referred to in the notice which follows.

*Transatlantic longitude, Duxbury, Massachusetts.*—When my last annual report was closed, Assistant George W. Dean had arrived at Brest on the coast of France, to exchange time-signals with Assistant Edward Goodfellow, who remained at Duxbury, working in a temporary observatory near the French cable office.

In procuring the authorization needful for his proposed telegraphic observations, Mr. Dean was cordially welcomed at Paris by the United States minister, Hon. E. B. Washburne, and his secretaries, Colonel Hoffman and Colonel Moore, and by their kindness was introduced to the naval secretary of France, who directed that every facility should be extended by the naval commander at Brest. This intention was cordially fulfilled. A station was selected by Mr. Dean in the grounds connected with the "*Establishment des Pupilles de la Marine,*" at a measured distance of one hundred and twenty-six meters from the nearest geodetic point of the survey of France, which is near the center of the tower in the church of Saint Louis. The inspector of the French telegraph lines, Monsieur G. Duval, furthered the operations proposed, by extending wires to connect the longitude station with the French cable office, which was about half a mile distant.

Astronomical observations were commenced by Assistant Dean and Sub-Assistant F. Blake, jr., at Brest, on the 27th of December, and continued until the 10th of February. In the favorable intervals between those dates the local time and instrumental corrections were determined by 290 observations on sixty-two zenith and circumpolar stars. The portable transit No. 4, adjusted upon two granite posts, was used for the purpose. Time was recorded on a Bond chronograph by a Frodsham break-circuit chronometer.

Acknowledgments are due for the friendly and valuable co-operation of Cromwell F. Varley, esq., of London, electrician of the French Telegraph Cable Company, who directed the arrangements needful at St. Pierre for joining the two parts of the cable, and made adjustments for the electromotive force, so that, as applied at Duxbury, St. Pierre, and Brest, the velocity, as far as possible, might be the same for all signals made in the determination of longitude. The length of cable through which the signals passed is 3,847 statute miles. Exchanges were successfully made, on ten nights of January and February, between Mr. Dean, at Brest, and Mr. Goodfellow, at Duxbury. Whenever practicable, during the exchanges with Brest, the chronograph sheets at Duxbury were graduated by the mean-time clock of the Cambridge Observatory, under the direction of Professor Winlock, and by the sidereal clock at Duxbury; and the signals sent to and received from Brest were recorded upon the chronographs at Duxbury and Cambridge.

For the purpose of measuring personal error in noting the cable-signals, Assistant Goodfellow arranged a circuit to pass through the clock and chronograph connections at his station, and through the cable-key and break-circuit key in the cable office at Duxbury. This circuit was worked by a battery of three Daniells cells, while the circuit for obtaining signals like those received during the longitude experiments was operated by a single cell of Menotti's battery, forty having been used for the electromotive force in passing signals to Brest. This second circuit included the galvanometer which had been used for longitude. The signals for personal error were given in the battery-room of the cable office, out of sight and hearing of the observer in another room of the building. Three sets of signals were thus noted on different days. The stars observed at Duxbury for local time and instrumental corrections were taken from the American Nautical Almanac, and from a manuscript list of stars, the positions of which had been determined under the direction of Professor Winlock, at the Cambridge Observatory, for the use of the longitude parties of the Coast Survey. Assistant Goodfellow recorded 447 observations upon 103 stars, among which were fourteen circumpolar stars observed for thread-intervals. After closing his observations, Mr. Goodfellow carefully marked the position occupied by the transit instrument. A granite pillar 21 inches long and 7 inches square was set in the ground and surrounded with curbing of oak, inside of which was placed a granite slab 28 inches square and 7 inches thick, supporting a 14-inch cube, also of granite. Copper bolts half an inch in diameter were inserted vertically in the tops of the upper and lower stones; the space left inside of the curbing was filled with sand. The point thus marked was referred by triangulation to a geodetic station, (West Duxbury spire,) and will ultimately be connected also with the primary station on Manomet Hill, on the coast of Massachusetts.

By previous arrangement, as stated in my report of last year, Professor Winlock co-operated in the reference of the transatlantic longitude to the Cambridge Observatory. On five nights, closing with the 3d of January, signals were sent from and received at the observatory and Duxbury. Assistant Goodfellow was aided by Mr. J. Laurence Wilde.

The computations needed for deriving from these observations the difference of longitude between Brest and Duxbury have been intrusted to Professor Joseph Lovering.

Assistant Dean, after returning from Europe, was engaged in duty which will be noticed under Section II. In November he joined the expedition of Professor Winlock, which was sent under my direction to observe the solar eclipse of December, 1870, at a station in Spain. Sub-Assistant Blake, after completing duty to which he had been assigned in Section III, was authorized to accompany the exploring expedition of the Navy which sailed for the Isthmus of Darien in December.

The favorable circumstances attending the outset of the work at Brest and Duxbury were referred to in my last annual report. It is agreeable to add that the operations throughout were furthered by the special liberality of officials who took pleasure in acts done in the interest of the people. Free transportation was accorded by George Mackenzie, esq., agent of the French line of steamers, in the shipment of instruments used in the observations at Brest. The report of Assistant Dean specially mentions also the ample facilities afforded by Thomas Andrews, esq., superintendent of the French cable at Brest, and by Mr. Gott, superintendent at St. Pierre, under favor of the credentials received at New York from L. G. Watson, esq., agent of the French Cable Company. In their movements the observers in France were much assisted by the care and attention of Monsieur Gustave Bossange, of Paris.

The Duxbury longitude station was connected with the cable office by wire furnished free of expense to the survey by Moses G. Farmer, esq., of Boston. R. T. Brown, esq., superintendent of the Duxbury Telegraph Station, contributed valuable assistance, as did also M. J. Gaines, esq., and the operators in the cable office, all aid being cordially tendered that could avail in the success of the operations.

The use of the land line of telegraphy between Duxbury and Cambridge, as in a number of previous instances, was freely accorded by the district superintendent of the Western Union Telegraph Company, J. F. Milliken, esq., who added to this courtesy his personal interest in the observations, as did also J. C. Upham, esq., manager of the line at Duxbury. The like spirit of liberality on their part has been the subject of acknowledgment on other occasions.

*Hydrography of Plymouth Bay and Duxbury Harbor, Massachusetts.*—After setting up a tide-gauge on Long Wharf at Plymouth, the party of Sub-Assistant Anderson started with boats and sounded out the shallow parts of Plymouth Bay, completing the hydrographic survey within the shore-lines. Additional lines of soundings were then run in Duxbury Harbor, completing the survey of that vicinity. This work is shown on Sketch No. 16.

Sub-Assistant Anderson is now on duty in Section VII.

The following comprises the statistics of soundings referred to under this and a preceding head:

| | |
|---|---|
| Miles run in sounding | 267 |
| Angles measured | 2, 866 |
| Number of soundings | 26, 092 |

The work at Plymouth occupied the party during the month of October.

*Reclamation of tide-lands.*—In a general way reference has been already made, in the introduction of this report, to complex questions likely to originate in attempts to reclaim land that is ordinarily covered by tide-water. Within the past year two sites were examined by Assistant Henry Mitchell. In both of them matter of much interest was presented in considering the general effect of the works requisite for producing the special result desired.

The vicinity of North River, on the coast of Massachusetts, was found specially interesting, as well from local peculiarities as from observed changes which the stream had suffered by movements of the shingle and sand along the coast during storms. There, as at other places, Mr. Mitchell carefully measured the shingle levees, and found the seaward slope to be the type toward which the dike-building of Europe has been tending. He shows, also, in his discussion of the subject, that their heights may be regarded as the measures of certain great storm-waves, and that their rearward slopes are those of least resistance to the escaping water of overflows. The effect of a dam in backing up the inland waters he computed for the conditions observed at North River in June last, and the heights to which the dikes should be carried, so as to protect the inclosed lands, were carefully determined. The problem of reclamation there presented is by no means a simple one, but the result of the study is, upon the whole, favorable.

The second case investigated was that of Green Harbor, a very simple one in the matter of drainage, but complicated in its relation to navigation. There seems to be little doubt that the depth of water upon the bar of this harbor is maintained by the tidal outflow, and that the depth must lessen after the construction of the proposed sluice-dam.

During part of the summer Assistant Mitchell engaged in physical researches in San Francisco Bay, mention of which will be made under Section X, in the body of this report.

After his return from service in the Darien exploring expedition, Sub-Assistant H. L. Marinden resumed his place, and has continued on duty in the party of Assistant Mitchell; Mr. F. H. North has served as aid, and his efforts are commended in the report of the season.

The topographical maps requisite for the investigations at Marshfield and Scituate were made in the field by Mr. O. H. Tittmann, under the general direction of Assistant H. L. Whiting.

*Triangulation of Narragansett Bay, Rhode Island.*—With a view to perfect the connection between the former work and the triangulation executed by Assistant S. C. McCorkle in 1869, and to supply points required by the topographical parties on the coast eastward of Saughkonnet River, Mr. McCorkle received instructions, immediately on his return from Section VII, to proceed to Narragansett Bay and to make the necessary observations. The work was commenced on the 17th of June and completed on the 16th of July, and, by the 22d, the computations were finished, and these, with the original and duplicate records, were forwarded to the office at Washington.

The statistics of the field-work are:

| | |
|---|---|
| Signals erected | 5 |
| Stations occupied | 7 |
| Angles measured | 30 |
| Number of observations | 480 |

Between the 22d of July and the 12th of August, Assistant McCorkle was engaged in computations connected with his work in Florida, and toward the close of the month he received instructions for duty on Lake Champlain, to which reference will be made in the next section.

*Topography of Narragansett Bay, Rhode Island.*—This survey has been advanced nearly to completion by the party of Assistant A. M. Harrison and others working jointly on the ground but with separate plane-tables.

The details of topography were resumed by Mr. Harrison early in July, and were mapped in to include the north end of Rhode Island, below Bristol Ferry, before the close of September. Assistant C. T. Iardella joined on the 23d of July, and worked with a detached party. Two other sheets were completed in the course of the season under the direction of Assistant Harrison. These include the vicinity of Newport and the lower part of the island between Narragansett Bay and Saughkonnet River. The topographical features are very intricate, involving broken shore-line, with reefs extending seaward; outlying rocks; rocky bluffs and fissures; and hills very irregular in contour. Few places immediately on an open coast embrace within a limited area such variety in surface details, and which, as likely to be permanent, are so proper to be included in the publication of the final chart of the bay, which is shown in Sketches Nos. 20 and 21.

Assistant Charles Hosmer commenced on the 3d of July, and continued in the field until the 12th of September. In the interval he traced the eastern shore of the Saughkonnet River, and made a detailed survey of the features between the shore and the road that runs nearly parallel to it, through Tiverton. In its character the sheet was made conformable to those previously done by Assistant Harrison, the several parties having conferred with him at the outset of the season, to insure that end.

Assistant Hosmer was aided in the field by Mr. A. P. Barnard.

Before engaging in the section, Mr. Hosmer had been on service in Section V, and has now resumed duty on the southern coast. In September and October he took part in field-work which will be described under Section II.

After his return, at the end of July, from service in the Darien exploring expedition, Sub-Assistant H. G. Ogden proceeded to Newport, and took in charge the topography of the eastern side of Rhode Island. His party kept the field until the 1st of December. In the course of the season Mr. Ogden mapped the ground about Sachuest Point, and, in connection with it, all the surface details found on the western shore of Saughkonnet River, as high up as the Stone Bridge road. At the south end of Rhode Island, this party pushed the detailed survey to the westward of Easton's Point and there joined with the work of Assistant Harrison.

To the northward and westward of Sachuest Point, the work of the two parties joins in the vicinity of Newport. Throughout, the surface features are quite intricate. Amongst the details represented on one of the plane-table sheets turned in by Sub-Assistant Ogden, are the Paradise Rocks. These are four nearly parallel ledges lying north-northeast and south-southwest within a width of about half a mile. The most westerly of the ledges is 173 feet high, and, in projecting into the sea, it forms the western side of the bight between Sachuest Point and Easton's Point.

On the east side of Saughkonnet River, Mr. Ogden made a topographical survey from Quicksand Pond westward to the immediate vicinity of Saughkonnet Point, and there connected with the detailed work of Assistant Hosmer. The aggregate area mapped by Sub-Assistant Ogden is nineteen square miles.

The statistics of work done by the three plane-table parties is as follows:

| | | |
|---|---|---|
| Shore-line | 90½ | miles. |
| Creeks and ponds | 58 | miles. |
| Marsh-line | 22¼ | miles. |
| Roads | 181 | miles. |
| Area of topography, (square miles) | 55 | |

Sub-Assistant Ogden is now conducting a field-party in Section VII. In December, Assistant Iardella joined a plane-table party in Section IV. Assistant Harrison continues the topographical survey of the shores of Narragansett Bay, and is yet in the field.

*Tidal observations.*—A self-registering tide-gauge of improved construction was put up and started on the 21st of January, at the station in North Haven, on one of the Fox Islands in Penobscot Bay. The instrument worked well during the winter and every precaution was used to prevent stoppages. There is good reason to expect a valuable series of observations at this station, the situation, apart from the severity of cold in winter, being particularly favorable. In another place a brief account has been given of the tide-gauge now in use at North Haven. The observer, Mr. J. G. Spaulding, has also kept a meteorological register, and during the past year has applied, for the prediction of tides at Boston, the formulæ deduced for that port by Professor Ferrel, whose discussion was printed in the appendix of my report for 1868.

This self-registering tide-gauge at the Boston navy-yard, in the care of Mr. H. Howland, has been in constant operation, except for a few severely cold days of last winter, when it was stopped by ice. The omissions in the record have been supplied from the register of an experimental gauge furnished with glycerine, which was in operation near the permanent gauge. Meteorological observations were recorded also at this station. As usual, short series of tidal observations have been made at several other places in the course of the season by the hydrographic parties. These are primarily for the purpose of reducing the soundings, but they also show the tidal relations between the principal stations.

## SECTION II.

ATLANTIC COAST AND SEA-PORTS OF CONNECTICUT, NEW YORK, NEW JERSEY, PENNSYLVANIA, AND DELAWARE, INCLUDING BAYS AND RIVERS. (SKETCH No. 3.)

*Reconnaissance near New Haven, Connecticut.*—A strong local interest having been manifested in regard to the extension of the topographical survey of the vicinity of New Haven beyond the limits given on the published chart of the harbor, an examination was directed with a view to the identification of stations which had been occupied in the original survey. The chart, moreover, was issued in 1846, and it was known that artificial changes made in the vicinity since that date had obliterated some of the points.

Assistant R. M. Bache reached New Haven in July, and in the course of the summer visited the principal stations of the triangulation. While so engaged the opportunity was taken to determine the heights of places of special interest in the vicinity of New Haven. A datum-mark for that purpose was made at the east end of Chapel Street Bridge, where the rise and fall of the tides were recorded during one lunation. Lines were run with the spirit-level and referred to the bench-mark, by which Assistant Bache determined the height of East Rock, West Rock, Rabbit Rock, and the elevation of other points in the neighborhood of New Haven. The results of these measurements were furnished to the city engineer and to the leading authorities of Yale College.

The triangulation about New Haven was made under the direction of Superintendent Hassler, previous to the re-organization of the survey of the coast. The marks then set at Mount Carmel and at Dickerman stations were found by Assistant Bache. At several others he was enabled to identify the sites by stones or other marks of reference left in the ground, but in no instance, except at the two stations mentioned, which are quite near together, could the position formerly occupied by the theodolite be closely ascertained. Nineteen sites in all were carefully examined at which marks had been placed by Mr. Hassler. The present condition of the ground at each is stated in the report of Assistant Bache.

*Survey of Lake Champlain, Vermont, and New York.*—The survey of the lake was commenced as soon as possible after the receipt of the information that it had been included among the duties assigned to the Superintendent. The assistants were detailed on the 25th of August and the parties were organized and at work early in September. Each special branch, as applied practically in the survey of the coast, followed one immediately after the other in the order of its precedence: first the reconnaissance and selection of a site for a base and for a scheme of triangulation; afterwards, in succession, the measurement of the base; the triangulation; the astronomical determination of latitude and azimuth at one of the trigonometrical points; the telegraphic determination of the approximate longitude of the same point by the transmission to Harvard Observatory of the local time at the station; the topographical delineation of the shores, based upon and checked by the triangulation; and, finally, the hydrography, showing the depth of water in the lake, its periodical rise and fall, the reefs, shoals, and dangers to navigation, and the havens and anchorages available when needed.

The survey, as far as it is done, embraces the broadest part of the lake, extending from Cumberland Head on the New York side to Sherburne Point on the Vermont shore, including the harbors of Plattsburgh and Burlington. The hydrography, being necessarily the last in order, was confined to the lower section from Plattsburgh Harbor to the island of South Hero.

Field-work was suspended towards the close of October, when the time had arrived for resuming operations on the southern sections of the Atlantic coast.

The want of proper facilities, which could not be collected on the emergency without considerable delay, retarded the progress of the field-parties. Nevertheless, the results obtained during the short season on the lake have been highly satisfactory. They are shown in a general way by the map which accompanies this report as Sketch No. 3. Mention will be made under separate heads of the several branches of work and of the assistants engaged in this survey.

*Reconnaissance.*—The reconnaissance was commenced by Assistant R. D. Cutts, on the 27th of August. A careful examination was made of the lake-shores, and of the country in the vicinity of Burlington and Plattsburgh, for a site of the character desired for a base-line. To avoid delay in other operations, a short preliminary base was measured for immediate purposes, and the reconnaissance was continued subsequently over a more extended section, for a length of line sufficient for the most accurate survey. After a comparison of the relative advantages of several sites for a preliminary base, the plateau lying south of Plattsburgh was selected, the ground being high, level, and tolerably free from obstructions, and so situated that it could be introduced directly at one of the most desirable localities for commencing the triangulation. The northern terminus is on the United States military reservation, and the line, passing through the reservation and across the land of Mr. Bentley Sherman, ends with the plateau itself, near Sherman's house. The preliminary measurement was made on the 10th of September, and the final measurement between the 12th and 16th, with the six-meter contact-slide apparatus, the rods of which had been compared with the Coast Survey standard, No. 2, a day or two before they were forwarded from Washington. The length of the base, corrected for inclination and temperature, is $1961^{m}.05$. The usual monuments were erected and underground marks adjusted and described for the preservation of the termini of the line.

Another secondary base was measured on the 19th of September, by Sub-Assistant F. W. Perkins, on the straight track of the Rutland Railroad, near the depot at Burlington, for the purpose of starting the topographical survey of the harbor. This line, $1319^{m}.76$ in length, was measured with a sixty-meter wire, the length of which had been obtained by means of the base-apparatus.

In the latter part of September and during the first week in October, the reconnaissance for a principal base was continued by Sub-Assistant Perkins, under the direction of Assistant Cutts. The most favorable site found is in Vermont, on the comparatively low ground bordering the lake to the westward of the town of Saint Albans. Its length is 5½ to 6 miles, and the site can be prepared for measurement at the proper season with but slight expenditure.

Sub-Assistant Perkins, Mr. F. Stover, and Mr. B. A. Colonna, temporary aids, are commended for intelligent services, in the field-report of Assistant Cutts.

*Triangulation.*—The limits of the triangulation to be executed during the months of September and October were arranged, under the direction of Mr. Cutts, to include the most important harbors and the routes most used by the commerce of the lake. The scheme and its connections were put in the charge of Assistants J. A. Sullivan and S. C. McCorkle. The former commenced work at Burlington, Vermont, and the latter at Plattsburgh, New York, and the junction of the two series of triangles was made on the intermediate and common line, Stave Island—Point Trembleau. The reconnaissance and the organization of his party were commenced by Assistant Sullivan on the 2d, and the erection of signals on the 6th of September. From the latter date until the 23d of October the work was prosecuted without interruption, except during the prevalence of high winds and the thick smoke from burning forests on the Ottawa.

The following is a synopsis of the results furnished by Mr. Sullivan:

| | |
|---|---|
| Signals erected | 17 |
| Points determined | 32 |
| Number of observations | 2,060 |
| Area in square miles | 85 |

Mr. Sullivan refers, in his report, to the zealous, energetic, and efficient services rendered by Mr. Colonna.

After the completion of the reconnaissance made from Burlington, in conjunction with Assistant Sullivan, for the purpose of laying out the plan of work and its division, so as to secure the connection of the base in New York with the astronomical station in Vermont, Assistant McCorkle proceeded to Plattsburgh and started a series of triangles from the base, working southward, and continued the field-work until the 15th of October, when the junction already referred to was completed.

The following statistics show the work executed by his party:

| | |
|---|---|
| Signals erected | 14 |
| Stations occupied | 12 |
| Angles measured | 186 |
| Number of observations | 1,488 |

Assistant McCorkle is now making preparations to take the field on the Gulf coast of Florida, and Assistant Sullivan is under instructions for duty in Section VI. During the first half of the surveying year he was in service in the Darien exploring expedition.

*Latitude of Burlington, Vermont.*—The astronomical station is on high ground within the city limits, and is connected with all the principal stations of the lake-triangulation to the westward. A temporary observatory was completed on the 12th of September. Transit No. 12 and zenith-telescope No. 4 were then mounted, each on a brick pier, sunk two feet below the surface, laid in cement, and capped with marble slabs. After careful attention to these preliminaries, Assistant A. T. Mosman commenced the observations, and by the 16th of October the latitude and azimuth were determined.

Thirty-two stars were observed on five nights for time; one hundred and forty-nine results for latitude were obtained by observations of 29 pairs of stars on nine nights; and, in addition, two series of observations were made for the value of the micrometer, and three sets for the value of the level of the zenith telescope.

*Azimuth.*—The azimuth of the line, "Astronomical station—Juniper Island station," was determined by 24 sets, each consisting of 12 pointings, 6 on the direct and 6 on the reflected image of Polaris; and to transfer this azimuth to other lines of the triangulation, 8 sets of angles were taken, each of 12 repetitions.

Mr. Edwin Smith served as aid, and Assistant Mosman highly commends him for energy and ability. Mr. Smith also read the chronograph-sheets and made the time-reductions for Assistant Dean, while that observer was engaged in determining the longitude of the station.

Mr. Mosman passed the preceding winter and spring in service with the naval expedition which explored the Isthmus of Darien for a ship-canal route. He is now engaged in the determination of latitude and azimuth at stations on the Gulf of Mexico.

*Longitude of Burlington, Vermont.*—The approximate difference of longitude between the astronomical station at Burlington and Cambridge observatory, was determined on the nights of September 26 and 28, and October 2. Assistant G. W. Dean reached Burlington on the 19th of September, and occupied the observatory, using the transit set up by Assistant Mosman, who, in conjunction with his aid, Mr. Smith, furnished all the assistance required for determining the longitude.

The local time was ascertained each night by observing eight or ten zenith and circumpolar stars, with transit No. 12, the time being recorded on chronograph No. 2, and by the Frodsham break-circuit chronometer, No. 3451, belonging to Cambridge observatory. As soon as the time had been observed, the break-circuit chronometer was taken to the telegraph-office and there connected in a circuit directly with one of the clocks at the Cambridge observatory. The comparisons of the Burlington chronometer with the Cambridge clock were recorded on the observatory chronograph, during five minutes each night, after which the chronometer was taken back to the astronomical station, and further comparisons were made with the two chronometers of Assistant Mosman, for the verification of the daily rate of the Frodsham chronometer.

Professor Winlock, director of Cambridge observatory, co-operated in the determination of the longitude.

The results are as follows:

| | m | s |
|---|---|---|
| September 26. Astronomical station, west of Cambridge observatory | 8 | 18.5 |
| September 28. Astronomical station, west of Cambridge observatory | 8 | 18.1 |
| October 2. Astronomical station, west of Cambridge observatory | 8 | 18.2 |
| | 8 | 18.27 |
| Cambridge observatory, east of Naval Observatory, Washington | 23 | 41.13 |
| Burlington station, east of Naval Observatory, Washington | 15 | 22.86 |

The results are given in more detail in Appendix No. 13.

Assistant Dean mentions the acknowledgments due for the liberality of General T. T. Eckert, superintendent of the Western Union Telegraph Company lines, in affording the free use of wires between Burlington and Cambridge, and for the facilities extended to the survey by the superintendent of the line, G. W. Gates, esq., and Messrs. G. F. Milliken and H. N. Drewry, managers of the respective offices.

After completing the observations at Burlington, Mr. Dean engaged as an observer in the expedition for observing the solar eclipse of December, on the coast of Spain.

*Topography*—On the 13th of September, Assistant H. L. Whiting, accompanied by Assistants F. W. Dorr and Charles Hosmer, reached Burlington, and on the 14th proceeded to Plattsburgh for conference with Assistant Cutts in regard to the scale, limits, and necessary checks for the detailed survey. With a view of running the shore-line embraced within the scheme of triangulation then laid out and commenced, a secondary base, as already stated, was measured near Burlington. At this base Mr. Dorr commenced with the plane-table while Assistant Hosmer started from the Plattsburgh Base; the junction of their respective surveys being at two points, one in the vicinity of Port Jackson and the other at Port Trembleau.

Assistant Dorr had transferred the charge of his party on the coast of Maine to Sub-Assistant H. M. DeWees, on the 5th of September, and on the 19th the topography of Burlington Harbor was commenced. Between that data and the 14th of October the following work was accomplished by the party of Mr. Dorr: Sheet No. 1 contains the shore-line from Shelburne Point to Apple Tree Point, including Juniper Island, and Dunder Rock, and the docks and breakwater at Burlington; Sheet No. 2, the shore-line from Apple Tree Point to Colchester Point, including the mouth of Onion River and two islands, some ledges, and the vicinity of the new light-house lying off Colchester Point; and Sheet No. 3, the shore-line from Point Trembleau on the west side of the lake, northwardly, to Port Jackson, including Port Kent, the mouths of the Ausable River, and Garden Island. The total number of miles of shore-line surveyed by this party was 38¾.

Assistant Dorr had suffered from rheumatism during the whole progress of his work, and became too unwell to continue it after the middle of October.

Mr. Bion Bradbury, jr., was attached to the party as aid and rendered acceptable service. Assistant Sullivan arranged the details of his triangulation with reference to the plane-table work, and kept Assistant Dorr supplied with points for its continuance.

Assistant Hosmer reached Lake Champlain on the 17th of September, and commenced the shore-line survey in the vicinity of Plattsburgh, and continued at work until the 13th of October, when the part assigned to him was finished. The party was then discharged, but, in consequence of the illness of Mr. Dorr, Mr. Hosmer returned to the field and completed the shore-line survey south of Point Trembleau, within the area of the triangulation. This was done between the 20th of October and the 2d of November. The number of miles of shore-line surveyed by him was 45½. Sketch No. 22 will show the condition of the survey of Burlington Harbor at the time of publication of this report.

Assistant Hosmer is now on field-duty in Section 5, where he had been engaged during the early part of the present year. The previous work of Assistant Dorr will be mentioned under the head of Section IV.

*Hydrography of Lake Champlain.*—On the 21st of September Assistant Charles Junken reached Plattsburgh, New York, and, under the direction of the Hydrographic Inspector, hired a small vessel, which, in the course of a few days, was fitted for service in taking soundings. The hydrography was at once begun and was prosecuted until the 1st of November. Assistant Junken accurately sounded the middle section of Lake Champlain, or from Cumberland Head southward to Valcour Island, including Cumberland Bay and Plattsburgh Harbor. Boisterous weather after the middle of October interfered with the progress of work, yet the results are very satisfactory, considering the time allotted and circumstances of the season. The depth found in Cumberland Bay and in the lake south of the bay varies from 4 to 8 fathoms, but a mile east of Valcour Island the depth is 38½ fathoms. Soundings in that part of the lake developed a narrow gorge, extending north and south, with bottom consisting of brown clay and mud.

The plane of reference adopted by Assistant Junken for the adjustment of soundings on his working-sheet is 2½ inches lower than the lake-level in October last, and 3 inches higher than the water-level of the year 1855, which is believed to be the lowest ever observed. A synopsis of hydrographic statistics is appended.

| | |
|---|---|
| Miles run in sounding | 215 |
| Angles measured | 3,254 |
| Casts of the lead | 9,248 |

Mr. Joseph Hergesheimer was attached to this party as aid.

*Hydrography, New York Entrance.*—A large part of the working-season, between June and December, was occupied by Assistant F. H. Gerdes in verifying the positions of sea-marks connected with the navigation of New York Bay and Harbor. At intervals, however, soundings were made, developing the character of the bottom at Diamond Reef. The water on the Oil Spot and on Flynn's Knoll was found, by careful soundings, to have shoaled in places; and the depths will be changed accordingly on the existing chart.

Assistant Gerdes was aided by Mr. C. P. Dillaway. The party used the schooner Dana for transportation.

After turning in the plane-table sheet containing his survey of the Quarantine Islands on the west banks in New York Bay, Mr. Gerdes mapped the ground opposite on the shore of Raritan Bay, including the vicinity of the railroad piers. He subsequently traced and laid down on another plane-table sheet the line of the New Jersey Central Railroad, which passes through Bergen Neck, the survey of which was made previous to the location of the line.

The hydrographic-sheet containing the soundings made this year at New York Entrance is now on file in the office.

*Buoys and sea-marks, New York Harbor.*—In the course of the season Assistant Gerdes made angular measurements, and carefully determined the positions of all the buoys and sea-marks pertaining to the navigation of the channels into New York Harbor. These include the beacons, light-houses, and buoys in the upper and lower bays, in Raritan Bay, in East River, in Long Island Sound, and in Fisher's Island Sound, the verification being extended eastward as far as New London on the coast of Connecticut. Of these aids to navigation, more than a hundred in number, several have been recently erected, but, from the data supplied by the work of Assistant Gerdes, the positions of all of them will be marked on the respective engraved charts. The manuscript chart turned in by Mr. Gerdes was accompanied by an elaborate report and ample notes of the measures taken to secure accuracy in the positions.

*Altitudes of primary stations in Pennsylvania and New Jersey.*—The heights, above mean tide, of the primary triangulation points in this section not having been measured, except in a few cases, it was deemed advisable to take up this duty and to commence with the series extending from the Hudson River to the Chesapeake Bay. From the examinations lately made by Assistant Farley of these stations, it was ascertained that the usual trigonometrical leveling could not be carried on without re-opening many of the lines at great expense and delay. It was, therefore, decided to determine their heights by lines of spirit-leveling from tide-water, in combination with careful observations of the mercurial barometer, and the entire operation was placed under the charge of Assistant R. D. Cutts.

The results have been highly valuable and interesting, as will be seen by reference to the abstract of the report of Assistant Cutts, (Appendix No. 8.)

The duty of running the lines of level was assigned to Sub-Assistant Charles Ferguson. During the month of June, Mr. Ferguson erected a tide-gauge at Keyport, on Raritan Bay, New Jersey, and determined the mean-tide by observations of high and low water during a semi-lunation. Starting from the half-tide, or common plane of reference, a tidal bench-mark was made in the village of Keyport, and the line was continued through Freehold, Clarksburg, Pemberton, Mount Holly, and Camden, to a tidal station and tide-staff at Gloucester City on the Delaware River, opposite to Philadelphia. From this main line, offsets were made to the primary stations of Beaconhill, Disborough, Stony Hill, and Mount Holly. These different lines were divided into sections, and each section was leveled in one direction, and re-leveled in the other, before proceeding to the next, the entire distance thus leveled being 180 miles. Bench-marks were established at all the principal points on the route, and these marks are duly described in the record. The tracks of the different railroads were used wherever practicable and in the general direction of the line.

The instrument and rods employed were of the most approved construction, and the method of adjustment and of observing in the field tested the readings and the even distances between the back and fore sights, and allowed the corrections for the recorded instrumental errors and the want of level at the moment of observing to be computed and applied to the readings on the rod.

Mr. Ferguson refers to the difficulties encountered as sources of delay, such as the deep sand on some part of the route, and the broken character of the country on the offsets to the trigonometrical stations.

The duplication of the records and the computations of the field-work are now in hand for completion at an early day.

*Barometrical observations—Pennsylvania and New Jersey.*—The height above the plane of reference of the three stations of Stony Hill, Mount Holly, and Gloucester City, having been obtained by the spirit-level, these heights were used as so many different bases from which to deduce and check the altitudes of the primary stations of Mount Rose, Newtown, Willow Grove, Yard, and Bethel, in Pennsylvania, and of Pine Hill and Lippincott, in New Jersey, obtained by means of the differences which were found to exist between observations, taken simultaneously, of cistern barometers stationed at the known and unknown points. The distances between the stations ranged from ten to twenty-five miles, and the observations were made at the most favorable season for uniformity in the density of the atmosphere.

The barometers and psychrometers, four of each, were constructed specially for this work by James Green, esq., of New York. Comparisons, one with the other, for differences, as well as for personal errors in the observers, were made at Mount Holly before the parties of Assistant Cutts separated for their respective stations, and similar comparisons were instituted on their return. The watch of each observer was also compared and its rate established, so that the comparatively small corrections for error and rate might be applied in each case in order to insure that all the observations should be taken at the prescribed time.

Five observations were made daily for ten consecutive days at each station, and each observation consisted of three separate readings of the instruments as a precaution against mistakes. The hours selected for observing were those believed to be, from the experience of reliable persons, the most favorable for obtaining the mean temperature of the column of air between the stations. The comparisons and observations were commenced July 9th, and ended September 13th.

The observers were Sub-Assistant F. H. Agnew, Messrs. Edwin Smith, Charles L. Gardner, and B. A. Colonna, aids, and Mr. Charles Wurdemann. Assistant Cutts reports that to their care, accuracy, and interest in each of the details, and especially to the assistance given by Mr. Agnew, the success of the operation is mainly due.

*Reconnaissance, New Jersey.*—Between Schenectady, in the State of New York, and Barnegat, on the coast of New Jersey, a triangulation of the first order is complete from Troy down through the valley of the Hudson River to the vicinity of the Palisades, where it joins with the primary triangulation of the Atlantic coast. Work of the same character not being practicable along the low sea-board of New Jersey, the primary work was deflected at New York City, and thence stretches to the southward and westward to the head of Delaware Bay. Two, however, of the primary stations in New Jersey being not far distant from Barnegat light-house, it is proposed to bring the three points into goedetic connection, and also to connect Schenectady with the triangulation of the Hudson, near Troy, New York. From these operations will result the measurement of an arc of three degrees along the meridian, or, the true distance north and south between Schenectady and Barnegat.

Assistant W. S. Edwards took the field early in November, 1869, and, after visiting Stony Hill and Mount Holly, made a reconnaissance of the two ridges intervening between those stations and the coast of New Jersey. The object sought was to avoid, if possible, the selection of points on the ridge nearest to Mount Holly, and thus to secure the connection of Barnegat with the least possible number of triangles. He kept the field until the 20th of December, after making notes for guidance in resuming the examination. Mr. Edwards was subsequently on duty in Section V; but before the opening of the season for again taking up work in Section II, he retired from the survey.

Under my instructions of June last, Sub-Assistant F. W. Perkins was directed to examine carefully all the reports, journals, and sketches heretofore made in reference to this subject and to continue the reconnaissance. Mr. Perkins reached Mount Holly on the 5th of July and commenced work without delay. High signals were erected at all the known intervisible points and on several elevations which could be made available for the desired scheme. At these points observations were made from temporary scaffolds or by climbing, at such times as there was any probability of seeing, until, by perseverance and careful selection, the duty was successfully accomplished. The scheme embraces four intermediate points between the base and the coast, and the triangles are satisfactory both in shape and size. The work was completed toward the close of August. In his report Mr. Perkins refers to the obstacles caused by smoke which covered the country during July and the early part of August, and to the unbroken second growth of wood and want of roads in the pine region.

Early in September Mr. Perkins was assigned to duty on Lake Champlain. He is at present employed in the triangulations in Section IV.

*Inspection of primary stations.*—This duty has been continued by Assistant John Farley. The four stations among the earliest determined for the survey of the coast, which could not be identified last season, have been re-examined. Excavations were made at "Bethel" and "Meeting-house Hill," but without result. At station "Weasel" the surface of the rock was cleaned, but without finding the copper bolt or the aperture in which it had been fixed, and the inference drawn by Mr. Farley is that as the point is near the edge of the precipice, "the abrasion of storms might have carried it over the precipice." In regard to "Lippincott," directions have been given that when the field is next plowed, a careful scrutiny should be made for the remains of the roots of the different trees to which references were made when the underground mark was deposited. If these clews can be obtained the approximate position of the center of the station will be found, and the cone can then be sought for.

*Topography of Reed Bay and vicinity, New Jersey.*—Plane-table work was resumed on the coast of New Jersey, by Assistant C. M. Bache, early in July, and was continued until the 3d of December.

In that interval the survey was extended from Great Bay southward to a line joining Absecom and Atlantic City. Westward the topography includes the road passing southward from Leeds Point. The district represented by the plane-table sheet is nearly filled with small bays, which are affected by the influx of tidal waters at New Inlet and Absecom Inlet. In the vicinity at which the tides meet the work proved to be difficult, the marsh being soft and indeterminate in outline. Notwithstanding the disadvantages due to the extreme heat of the summer, three hundred miles of water-line were traced in the course of the season within an area of forty-three square miles. The working-sheet includes, also, ten miles of road.

Sub-Assistant H. W. Bache was attached to the party and assisted in the field-work. In passing to and fro to define the numerous water-channels, the operations of Assistant Bache were facilitated by the use of a barge of light draught and adapted in other respects to service on the coast of New Jersey. This party had been previously employed in Section V.

*Tidal observations.*—The permanent series of tidal observations in New York Harbor has been kept up, with the self-registering gauge on Governor's Island, by Mr. R. T. Bassett, an experienced observer, who has also, from time to time, registered day-tides with a box-gauge at the Hamilton Avenue Ferry, in Brooklyn. A few years more will complete this important series, and furnish the means for final discussion, and data for predicting the tides at the port of New York.

## SECTION III.

### ATLANTIC COAST, AND BAYS OF MARYLAND AND VIRGINIA, INCLUDING SEA-PORTS AND RIVERS. (SKETCHES NOS. 4 AND 5.)

*Primary triangulation near Washington, District of Columbia.*—After his return from Section V in June, Assistant C. O. Boutelle resumed, at Peach Grove, Virginia, the observations which he had commenced at that station before the close of the preceding season. Owing to the extreme heat of July, but few observations were possible in that month. The angular measurements due at Peach Grove were completed near the middle of August. Soon afterwards the party was transferred to Maryland Heights, near Harper's Ferry. There, in addition to the measurement of angles, by Assistant Boutelle and his aid, Mr. A. H. Scott, latitude and azimuth observations were made by Sub-Assistant F. Blake, jr.

After turning in the astronomical records Mr. Blake was detached from the party, with permission to join the second naval exploring expedition which sailed for the Isthmus of Darien in December last.

*Triangulation. Chesapeake Bay and James River.*—At the date of my last report the base of verification at the entrance to the James River had been measured and the observations for connecting it with the triangulation of Chesapeake Bay had been commenced by Assistant R. E. Halter. During the month of November, 1869, the work advanced under the temporary charge of Sub-Assistant F. W. Perkins. In the following month the schooner Bowditch was repaired and fitted for the use of the party, after which Assistant Halter resumed work at Sewall's Point, and by March 21st the connection of the base with the primary triangulation was effected on the line Back River light-house–Cape Henry light-house, and the agreement ($\frac{1}{107000}$) was entirely satisfactory. On the completion of this duty Mr. Halter returned to the base and carried the triangulation up the James River, stopping on the 1st of August at the line, Jamestown-Jones. The work was resumed on the 1st of October, and on the 1st of November, the date of his report, Mr. Halter had erected signals to carry the triangulation as far as the mouth of the Chickahominy.

The work was considerably retarded during the winter by high winds, and somewhat by ice, and, during July, by sickness in the party.

The statistics for the season are as follows:

| | |
|---|---|
| Light-houses occupied | 3 |
| Light-houses used as signals | 7 |
| Signals erected | 25 |
| Stations occupied | 22 |
| Number of observations | 7, 564 |

The progress made and character of the work executed by Assistant Halter are highly satisfactory. His party will continue in field-service during the winter.

*Topography, including the Broad Water, coast of Virginia.*—The party of Assistant J. W. Donn, under the advantage of a favorable winter, made a large advance in the survey of the outer coast of Virginia, north of Cape Charles. Before the opening of spring the plane-table survey included the ground between Chesapeake Bay and the Broad Water, the limits north and south being Eastville and the head of Magothy Bay. Subsequently it was extended northward and eastward, and has taken in the channels, islands, and marshes which mark this part of the Atlantic coast. Frequent storms much interrupted the progress of work along the sea-board. Of the vicinity of the Broad Water a sheet remains to be finished, which will include the northern part, and on this Mr. Donn and his aid, Mr. L. B. Wright, are now engaged. The survey was suspended during the summer, when the party was engaged on another part of the coast, as mentioned under Section I. A synopsis of the statistics of work done on the coast of Virginia, appended to the field-report of Assistant Donn, shows an aggregate of 359 miles of shore-line traced, and 144 miles of road, within a mapped area of 147 square miles.

*Hydrography of the Broad Water, Virginia, and of the Chesapeake estuaries, Maryland.*—With data furnished by the plane-table party, Sub-Assistant W. W. Harding commenced soundings in the latter part of July, and by the end of September developed the Broad Water, on the outer coast of Virginia, within the limits of the topographical survey. The hydrographic party in the schooner Hassler was previously at work in the Maryland branches of Chesapeake Bay. More than eighty of the estuaries were traced in outline and sounded in the course of the season by Sub-Assistant Harding and his aid, Mr. A. F. Pearl. These include the lesser rivers, as the Chester, Saint Michael's, the Choptank, and the Sassafras Rivers. Eastern Bay, one of the larger branches of the Chesapeake, was sounded out, as were also the Bush River and the Gunpowder. The shore-line survey and the hydrography were in all cases extended to the head of the tide. No intervals occurred in the progress of the work during last winter, except such as were necessary for procuring provisions for the crew. In the very numerous sites in which the operations were carried on, an aggregate of nearly two hundred miles of shore-line was traced by the hydrographic party. The tides were observed as usual, when needful for the adjustment of the soundings. Mr. Harding closed on the 9th of December in order to report progress in the work now under notice. The aggregate statistics are as follows:

| | |
|---|---|
| Signals erected | 65 |
| Angles measured | 286 |
| Miles run in sounding | 518 |
| Number of soundings | 31,567 |

The party in the schooner Hassler is now engaged on the Chesapeake indentations that remain to be defined in order to complete the hydrography of the bay.

*Magnetic and astronomical observations.*—In order to preserve the continuity of the series of observations begun in January, 1867, and for the accumulation of data bearing on the secular change, Assistant Charles A. Schott observed in June last, and deduced the magnetic declination, dip, and intensity at a station in his own grounds to which the instruments were transferred in advance of the removal of the Coast Survey Office. The new office-site not admitting of the erection of a suitable out-building, the series will be continued annually at the station occupied this year, which is at the southeast corner of the intersection of Second street east with C street south, and about five hundred yards east of the Coast-Survey Office.

At the request of Brigadier-General Albert J. Myer, Chief Signal-Officer of the Army, Mr. Schott assisted during several days in August in organizing the system by which observations of the weather generally, and reports on storms since that time, have been made public for the benefit of commerce.

In October he accompanied me in the voyage to Europe, and took charge of the party details for observing, under my immediate direction, the phenomena of the solar eclipse of December last. The observations made by my party at Catania, on the island of Sicily, will be discussed in a subsequent report to the Department. After his return from Europe, Assistant Schott resumed his place in the office as chief of the Computing Division.

*Tidal observations.*—At Old Point Comfort, Virginia, observations were continued with the self-registering tide-gauge by Mr. E. F. Krebs until the 1st of May, when he resigned. Mr. W. T. Bodell is now in charge of the station. This is one of our most extended series of observations, but, unfortunately, parts of it are imperfect in continuity. Last winter one of the severe storms swept away or rendered useless all parts of the apparatus that were under water. With these drawbacks, however, the series is valuable, and will furnish important results by discussion. This station is, of necessity, much exposed to the force of the sea.

In this section several short series of tidal observations have been made in hydrographic operations, at places on the Chesapeake and in rivers which empty into that bay.

## SECTION IV.

ATLANTIC COAST AND SOUNDS OF NORTH CAROLINA, INCLUDING SEA-PORTS AND RIVERS. (SKETCH No. 6.)

*Hydrography, coast of North Carolina.*—While the steamer Bibb was under repairs in June, Acting Master Robert Platt, United States Navy, assistant Coast Survey, employed a sufficient force from his crew, in charge of Sub-Assistant Gershom Bradford, to set up signals along the coast of North Carolina, to the northward of Cape Hatteras. The coast-hydrography was then resumed abreast of Albemarle Sound, and was extended southward to Loggerhead Inlet. As represented by the chart, the depth is uneven; soundings were consequently made more numerous than is usual in developing bottom along the open sea-coast. Off Bodies Island shoals were found giving only 4½ and 5 fathoms of water, while the depth between them and the coast is 12 fathoms and in some cases more. In reference to that vicinity, Acting Master Platt says: "It would be a hard matter to give sailing directions; I can only recommend the constant use of the lead. No part of the coast is more in need of a light-house, for the land at Bodies Island is so low that it cannot be seen on the clearest day from vessels more than four or five miles off, and the soundings being irregular, would deceive the most watchful navigator." It is suggested in the same report, as a collateral advantage, that a light-house on Bodies Island would serve as a guide to the Wimble Shoals, which lie at the only bend made by the Atlantic coast between Cape Henry and Cape Hatteras. Mr. J. B. Adamson aided in the hydrographic operations.

This work was prosecuted until the close of September. The party had been previously engaged on the Florida reef, and will be employed there during the present winter. Further reference to the service of Acting Master Platt will be made under the head of Section VI.

Sub-Assistant Bradford has been assigned to duty on the Pacific coast.

In October, soundings were resumed on the coast of North Carolina, at New Inlet, so as to join with the work which was suspended at Loggerhead Inlet in the preceding month. Bad weather occasioned much delay in pushing the hydrography southward. Twice the steamer was driven back to her anchorage in Hatteras Inlet, and was there detained twenty-two days. Acting Master Platt took the first favorable opportunity and pushed the coast-soundings southward to Cape Hatteras, closing the work late in November.

Close to the shore some few small shoals were developed below Loggerhead Inlet, but they are not in the ordinary track of vessels that pass coastwise. The bottom as shown by the chart is remarkably even between New Inlet and Cape Hatteras. Changes have occurred since the issue of the chart of Hatteras Inlet, and it is advised, in the report of Acting Master Platt, that vessels should not attempt to enter without a pilot, the anchorage inside being narrow and the current very strong.

The resulting chart is represented by the following statistics:

| | |
|---|---|
| Miles run in sounding | 919 |
| Angles for position | 2,047 |
| Number of soundings | 11,432 |

*Triangulation of Pamplico River, North Carolina.*—The field operations in this section, under the charge of Assistant G. A. Fairfield, have made excellent progress during the past year. The success of the party is due to the very favorable weather and to the good judgment shown in the arrangement of the work as to precedence of locality in regard to time.

Assistant Fairfield reached New Berne on the 14th of December, and after attending to the necessary repairs of the schooner *Dana*, proceeded to the Sound in the week following. During the months of January, February, and March, the usually boisterous season in the Sound, he completed the triangulation of Pamplico River, from its entrance at Judith Island to the head of navigation at the town of Washington, a distance of 40 miles, and also the triangulation of South Creek. Sub-Assistant F. W. Perkins efficiently assisted in this work. The computations were kept up with the progress in the field, and, on the 7th of April, the results were supplied for the use of the topographical and sounding parties. The next duty was in the Sound. Observations required at the primary stations Brant Island, Brant Island light-house, and Royal Shoal light-house, upon Swan Quarter Signal, were completed by the 22d of April.

The measurement of the base of verification, the site of which was selected in the previous season in the vicinity of Ocracoke Inlet, was next taken up. The base apparatus, sent from the office in Washington, in charge of R. L. Hawkins, esq., was shipped at New Berne on the 5th of May, and on the 9th the schooner was moored close to the intended line. Between that date and the 24th the line was traced and measured, the ends were securely marked, and signals were erected. The base is situated on the sand-flat forming the seaward side of Portsmouth Island, immediately south of Ocracoke Inlet, and extends from the village of Portsmouth to Whalebone Inlet. Its length, corrected for the inclination and temperature of the rods, is 9,038–39$^{m}$, (5.6 miles.) The measurement was made with the six-meter sliding-contact apparatus, according to the method heretofore used in the survey, and with all the care and precision prescribed for the operation. The contacts were adjusted by Assistant Fairfield in the measurement, and he observed also the inclinations of the rods, and the temperatures. Sub-Assistant Perkins kept the record of the operations and made the vertical offsets. The alignment of the bars was made by Mr. W. B. Fairfield, temporary aid.

At the close of May, the schooner *Dana*, with the base apparatus on board, was sent to Baltimore, and the duplicate records, &c., to the office at Washington. The originals and computations followed early in July.

The statistics of the work executed are as follows:

| | |
|---|---|
| Signals erected | 41 |
| Points determined | 44 |
| Stations occupied | 34 |
| Angles measured | 200 |
| Single observations | 4,832 |

*Topography of Pamplico River, North Carolina.*—In continuation of the field-work of this section, Assistant F. W. Dorr resumed the plane-table survey in January, using, as heretofore, the hull of the steamer Hetzel for the transportation needed in his operations. The vessel was towed from New Berne to the mouth of Pamplico River, by Captain Carson, of the revenue-steamer *I. I. Stevens*, which courtesy is duly acknowledged in the report of Assistant Dorr.

The topography of the western shore of Pamplico Sound had been advanced last season from the mouth of the Neuse River to Pamplico light-house. There the party started for the plane-table survey of Pamplico River. By reason, however, of its width, and of the extent of the branches of the river, it was found impracticable to include much of the northern shore on the first working-sheet. On the south side the shore-line was traced from Pamplico Point upward to Lee's Creek, and also the adjacent topography, marked by the branches of the lower part of Pamplico River. Of these the principal are Oyster Creek, Goose Creek, Bond's Creek, and near it South Creek. Of the upper side the survey includes the mouth of Pungo River, the largest estuary of the Pamplico, and also North Creek and Sinclair's Creek. Several of the streams shown on the plane-table sheets are navigable, and in particular South Creek and Bond's Creek, on which last is the growing settlement known as *Oregon Mills.*

Sub-Assistant H. M. De Wees was attached to the party at the outset of the season. During his absence of some weeks in the spring the work was continued by Mr. Dorr, without aid. He was rejoined by Mr. De Wees before the middle of April, and the survey was pushed until the 15th of June.

The return by statistics is as follows:

| | |
|---|---|
| Shore-line surveyed | 215 miles. |
| Streams | 193 miles. |
| Roads | 198 miles. |
| Area, (square miles) | 140 |

Mention has been made, under the head of Section I, of the work subsequently done by this party; and, under Section II, of topography in which Mr. Dorr was engaged. He is now in the field in Section IV.

*Hydrography of Pamplico Sound, North Carolina.*—In four different sites the hydrography of Pamplico Sound has been advanced by the party of Assistant F. F. Nes. Long Bay has been sounded, and the mouth of Pamplico River. Brant Island Shoal has been developed, and additional soundings have been made to the southward of Royal Shoal light-house in Pamplico Sound.

Work in this section was resumed on the 28th of December, 1869, with the schooner *Arago* and steam-launch *Scuppernong.* After prosecuting the soundings for a period of about ten days, the party was transferred to Cape Fear entrance and there engaged for a fortnight in a special survey, which will be noticed separately. Resuming work, at the end of January, in Pamplico Sound, the hydrography was prosecuted vigorously as far as the conditions of the weather would permit. Early in February, during a gale, the launch was sunk and the port anchor of the Arago was lost. Bad weather was frequent until April, but by improving short opportunities Assistant Nes completed soundings between Point of Marsh and Portsmouth, North Carolina, by the 6th of that month, and extended the hydrography of the sound so as to include Long Bay and the Thoroughfare, to Core Sound. The vicinity of Brant Island Shoal was sounded by the 13th of April, and between that date and the 4th of June, soundings, continuous with the general hydrography, were made at the entrance of Pamplico River, the work there being carried as far in as Indian Island. Before returning the vessel to New Berne, Mr. Nes ran several lines of soundings in the quarter, which will be developed by the hydrographic operations now in progress and to be continued during the winter. Mention was made under Section I of the operations of this party during the summer and autumn. A synopsis is appended of the statistics of work in Pamplico Sound:

| | |
|---|---|
| Miles run in sounding | 1,059 |
| Angles measured | 3,330 |
| Number of soundings | 92,442 |

Assistant Nes was aided by Messrs. C. P. Dillaway and Joseph Hergesheimer.

*Hydrography of Cape Fear (western) entrance, North Carolina.*—The western entrance to the Cape Fear River was sounded in January, 1870, at the instance of public authorities, in advance of their contemplated action for the improvement of the navigation. The results show that the bar has moved inwards and that the Rip Channel has deepened since the year 1865, and, on the contrary, that the Bald-Head Channel is now almost entirely closed. The changes noticed, and a copy of the chart made in January, were communicated early in the following month, for public purposes, to the Hon. J. C. Abbott, United States Senator from North Carolina.

This work was done by the party of Assistant Nes, as already stated, during the interval in the regular operations in this section. The statistics are as follows:

| | |
|---|---|
| Miles run in sounding | 84 |
| Angles measured | 592 |
| Number of soundings | 4,742 |

The party of Assistant Nes is now employed in Pamplico Sound.

## SECTION V.

### ATLANTIC COAST AND SEA-WATER CHANNELS OF SOUTH CAROLINA AND GEORGIA, INCLUDING SOUNDS, HARBORS, AND RIVERS. (SKETCH No. 7.)

*Reconnaissance near Winyah Bay, South Carolina.*—The secondary triangulation of the coast between Charleston and Winyah Bay was made in 1857. With a view to commence the detailed survey, Assistant W. S. Edwards received instructions at the close of January to proceed to Charleston and examine the stations, and, if additional points were necessary, to supply them. With a small fishing-smack, chartered for the purpose, the examination was conducted, and closed on the 15th of April. Of thirty-four stations visited, Mr. Edwards identified the marks at seventeen. Four of the remaining stations had been washed away, and at two others batteries had been erected in the course of the war. Another of the stations was obliterated by the erection of large salt-works.

Assistant Edwards reported that the points recorded, all of which were re-marked and described by him, are so situated as to afford a basis for the topography without additional triangulation. Before leaving the field he made a sketch of the inland passage from Breach Inlet to Cape Roman, showing the anchorages, the channels to the stations and landings, the local names, &c. This has been deposited in the office for future use. Previous reference to the services of Mr. Edwards was made under the head of Section II.

*Primary triangulation near Savannah, Georgia.*—During the spring Assistant C. O. Boutelle continued the preparation of lines below Port Royal for extending the primary triangulation southward to the Savannah River. The last avenue was cleared early in May, for bringing Tybee lighthouse into sight from a station on Daufuskie Island. With the theodolite Mr. Boutelle then occupied in succession five stations which he had previously rendered intervisible, and made the usual number of measurements for horizontal angles. The Exchange, in the city of Savannah, was occupied as a station, and finally Tybee light-house, where the connection was perfected in the geodetic work between Charleston Harbor and the Savannah River. Mr. Boutelle closed operations in this section early in June, and then took up duty in Section III.

Special difficulties have attended the primary work on the coast and sea islands of South Carolina. The triangulation had been carried easterly from the Edisto base to Charleston, and westward to Port Royal Bay, when the breaking out of the war in 1861 suspended all operations not absolutely essential for naval or military purposes. In its previous progress, the work, by reason of the flatness of the ground, had been a laborious operation, and at best only allowed a system of single triangles, with no quadrilaterals. Artificial elevations were required at every station to overcome the natural curvature, and these served also to keep the lines of sight above the stratum of air, which was generally disturbed close to the surface of the earth. Nearly every line had to be traced throughout its entire length with a transit instrument, to insure that it encountered no insuperable obstacle, such as a house or a grove of ornamental trees. Avenues through pine and other forest trees were required. These varied from mere "margins" of timber, surrounding cotton-fields, to unbroken lines of forest, from one to seven miles long. All of the lines were opened to a width of twenty feet.

The secondary triangulation was made to precede the primary and to exhibit for it the lines of least cutting. Later in the work, the topography went also in advance, and thus the degree of labor encountered in earlier years in selecting the primary stations has been much lessened.

On resuming the main triangulation after the war, it was decided to extend it south of Port Royal Bay and to close for the present at Savannah. This completed scheme connects the astronomical station at Breach Inlet, near Charleston, with the Savannah Exchange, which is also an astronomical point, and verifies the two secondary base-lines, which were measured for the surveys of Charleston Harbor and Savannah River.

In the concluding season of the primary work, observing tripods and scaffolds were erected at four stations, exclusive of other artificial elevations, as the Savannah Exchange and Tybee light, which, as before stated, were occupied as primary points.

Angular measurements were made during the season at twenty stations, including secondary points, and 137 angles were determined by 5,702 observations. The instruments used were the twelve-inch Gambey theodolite, (No. 16,) and the eight-inch Gambey, (No. 24.) Mr. Boutelle also made the usual magnetic observations, with Coast-Survey theodolite-magnetometer, No. 3.

The chief labor of the work, however, has been in rendering the primary stations intervisible. In the season of 1869–'70, this service occupied five months, while the primary angles observed through the avenues thus opened were measured in six weeks. Thus the preliminary labor required about three-fourths of the whole time employed in the triangulation.

The results of the primary work show a fair degree of precision in the secondary bases above referred to, and prove also that the secondary triangulation which has passed along the coast of Georgia may be confidently relied on, when checked by occasional astronomical stations and secondary base-lines.

*Topography of Broad River, South Carolina, and Savannah River.*—The working-force of Assistant Charles Hosmer was dispatched from Baltimore in the schooner G. M. Bache, on the 10th of December, 1869, but the vessel was disabled by severe gales at sea, which delayed her sailing from Norfolk until the 10th of January. To the hardships thus entailed was added, on the passage southward, the serious illness of the captain, making it necessary to put into New Berne, from whence the schooner finally sailed, and reached Savannah on the 2d of February. The topography was taken up without delay, and was prosecuted until the end of April. Assistant Hosmer first mapped the northern side of the Savannah river, opposite to Elba Island, so as to include the upper waters of Wright's River. To the northward and eastward he subsequently surveyed the vicinity of Bluffton and below it for several miles the courses of May River and Mackay's Creek; the first a tributary of Calibogue Sound, and the last, of Broad River. After laying up the vessel near Savannah, Mr. Hosmer reported at the office, and was assigned to duty in two of the northern sections. The statistics of work done by his party on the coast of South Carolina are here appended:

| | |
|---|---|
| Water-outline traced | 72 miles. |
| Marsh-outline | 24 miles. |
| Roads | 27 miles. |
| Area of topography, (square miles) | 28 |

See Sketch No. 17.

*Topography of Saint Andrew's Sound, Georgia.*—Assistant C. M. Bache reached Darien on the 6th of January, and took charge of the schooner Bailey for the use of his plane-table party. With stores on board, the vessel was taken to Fernandina and partially refitted for the service of the season. Assistant Bache, with his aid, Mr. Edwin Smith, then proceeded to fill in topographical details in the vicinity of Saint Andrew's Sound, the shore-lines having been traced in a previous season.

Sub-Assistant H. W. Bache joined the party early in April, and assisted in the field-work until the completion of the detailed survey, which was closed late in June. The topographical features within an aggregate area of twenty-five miles were mapped on the plane-table sheet. Assistant Bache then laid up the vessel near Savannah, and, after his return to the North, engaged in plane-table duty in Section II, as already mentioned.

The survey of this season by the party on the coast of Georgia includes part of Jekyl Island; the necks of land between the Great and Little Satilla Rivers, and the ground adjacent to the passages that form the water-communication between Saint Simon's Sound and Cumberland Sound.

A synopsis of statistics is appended:

| | |
|---|---|
| Shore-line traced | 165 miles. |
| Roads | 17 miles. |
| Area, (in square miles) | 25¼ |

*Topography of Cumberland Island and vicinity, Georgia.*—The plane-table work outstanding on the coast of Georgia at the opening of the season has been nearly completed by the party of Assistant W. H. Dennis. Cumberland Island was surveyed between the close of December and the end of May. On the same topographical sheet, Mr. Dennis and his aid, Mr. O. H. Tittmann, mapped the details lying to the westward, comprising all the water-passages that intersect the coast of Georgia in this vicinity. Of these the principal are known as Cumberland River, Brick Kiln River, Crooked River, and King's Bay. All of them form parts of the tide-water communication between Saint Andrew's Sound and Cumberland Sound, inside of the sea coast. Steamers plying between Savannah and Florida constantly pass by the interior route.

This survey was made with the schooner Caswell. For the use of the hydrographic party, Mr. Dennis determined points on the eastern side of Cumberland Island, and furnished tracings of shore-line to guide in making the soundings. The plane-table statistics are as follows:

| | |
|---|---|
| Shore-line of navigable waters | 135 miles. |
| Creeks and marsh-line | 104 miles. |
| Roads | 40 miles. |
| Area, (square miles) | 82 |

After this service Mr. Dennis and Mr. Tittmann engaged in field-work in Section I. Assistant Dennis is now employed in Section VI.

*Hydrography seaward of Cumberland Island, Georgia.*—The space intervening between the approaches to Saint Andrew's Sound and Cumberland Sound was occupied by the party of Assistant Charles Junken from the 27th of December, 1869, until the 6th of May following. After sounding thoroughly to seaward abreast of Cumberland Island, the party in the steamer Endeavor sounded also the tidal water-passages westward of the island, within the working limits of Assistant Dennis, who supplied tracings of the shore-line for hydrographic uses.

Outside of Cumberland Island Stafford's Shoal was developed, and the soundings generally were in that vicinity extended seaward to the depth of seven fathoms.

Assistant Junken was aided by Messrs. W. I. Vinal and G. W. Bissell.

The following is a synopsis from the hydrographic sheet:

| | |
|---|---|
| Miles run in sounding | 821 |
| Angles determined | 7,080 |
| Number of soundings | 44,118 |

The aids of this party were subsequently employed in Section I and Assistant Junken in hydrographic duty in Section II.

## SECTION VI.

### ATLANTIC AND GULF COASTS OF THE FLORIDA PENINSULA, INCLUDING THE REEFS AND KEYS, AND THE SEAPORTS AND RIVERS. (SKETCH NO. 7.)

*Hydrography of Saint Augustine Harbor, Florida.*—In order to determine the character of the changes which have occurred within the last ten years, the bar and harbor of Saint Augustine were sounded, in the course of the present season, by a party in charge of Sub-Assistant Horace Anderson. The entering channel was found to have shifted northward nearly a mile. As the entrance now is, vessels drawing as much as fifteen feet can enter at high water. Mr. Anderson commenced this survey in the middle of January. Three tide-gauges were set up; one at Saint Augustine, on the steamboat wharf; another in the river, north of the city; and the third at a point near Matanzas Inlet. Observations were recorded for sixty days with the tide-gauge in the harbor, and for short periods with the others.

After concluding work on the bar and in the harbor, Sub-Assistant Anderson extended soundings to include about fifteen miles of the course of North River, above Saint Augustine, and the Matanzas River as far southward as Matanzas Inlet. Work was closed on the 14th of April. The statistics are here appended:

| | |
|---|---|
| Signals erected | 59 |
| Points determined | 64 |
| Theodolite and sextant angles | 2,106 |
| Miles run in sounding | 186 |
| Casts of the lead | 26,813 |

The vessel assigned for use to this party, being barely sea-worthy, was dismasted during a gale in the intended transfer to Saint Augustine, and could not be further employed in the service. By permission from the honorable Secretary of War, Mr. Anderson occupied, temporarily, the United States barracks at Saint Augustine, but, in pushing the soundings north and south of the city, was under the necessity of working from a camp. He was efficiently aided by Mr. R. B. Palfrey.

Under Section I mention has been made of the subsequent occupation of Sub-Assistant Anderson. He is now in charge of a hydrographic party in Section VII.

*Topography of Chatham Bay and Barnes' Sound, Florida.*—The plane-table survey of the shore-line and keys of the northeastern part of the bay of Florida, known as Chatham Bay and Barnes' Sound, was assigned at the opening of the year to the party of Assistant J. G. Oltmanns.

Of the main-land of the peninsula of Florida, east and west of Cape Sab , the shore-line has been traced to a distance of nearly thirty miles, the limits this season joining with the work of previous years, and making the shore-line survey of the southern extremity of the peninsula continuous. The coast represented by the plane-table sheet is much broken by small creeks and covered with a heavy growth of mangrove and other trees. Most of the keys of Barnes' Sound are surrounded by extensive mud-flats, or by water so shallow as to make the approach to them very difficult. Some of the keys, however, are covered with water at high tides. One hundred and thirty-six of them are shown on the sheet which has been returned to the office. This plane-table survey comprised also the northwest side of Key Largo.

In connection with the field-work the party of Mr. Oltmanns completed the hydrography within the limits of his topographical sheet. The operations were carried on over an area of more than three hundred square miles.

The following is a synopsis of statistics taken from the original sheet:

| | |
|---|---|
| Shore-line traced of main-land | 74 miles. |
| Shore-line of island and keys | 178 miles. |
| Outline of shoals, &c | 56 miles. |
| Area of topography, (square miles) | 48 |
| Miles run in sounding | 76½ |
| Number of soundings | 1,035 |

The schooner Agassiz, used for the service, required extensive repairs in February, and the progress of the party was, in consequence, somewhat delayed.

The health of Assistant Oltmanns being greatly enfeebled by disease, a large part of the work was done by Mr. Eugene Ellicott, his aid, to whom Mr. Oltmanns gave credit for efficient services. After closing the work in May, the party was transferred to Section VIII, and instructions for operations during the summer were issued. But the health of Mr. Oltmanns entirely failed before the esrvice could be taken up. His lingering illness was closed by death on the 2d of September.

In July Mr. Ellicott was assigned to topographical duty in Section I.

*Hydrography of the Florida Reef.*—Soundings were resumed early in February at the western end of the Florida Reef by the hydrographic party in the steamer Bibb, under command of Acting Master Robert Platt, United States Navy, Assistant in the Coast Survey. In the course of a few days a tide-gauge was set up, and also two large signals to guide in sounding beyond the Marquesas. The running of the lines, however, was postponed for a fortnight, the calm in that interval being chosen by the steamer for towing the United States Monitor Saugus to Havana. Hydrographic work was resumed without further delay, and continued in the vicinity of the Quicksands until the 26th of March, when, by official request, the Bibb sailed for Havana and Santo Domingo, with naval dispatches. This duty employed the party until the 18th of April, when the ship was again coaled at Key West and proceeded to her station near the Marquesas. The adjuncts provided as signals were further improved by the use of two iron buoys, moored so as to be secure against the force of the wind or the sea. At these, boats were stationed, the sails and flags of which were observed on by the aids of the party, while the steamer was used in sounding. By means of the signals erected and the subsidiary expedients just referred to, a very difficult piece of work, made so by the absence of any natural leading mark on land, was successfully accomplished.

On the outer reef, off the Marquesas Island, Acting Master Platt found a rock with but 12 feet of water on it. Three miles north of the Quicksands, a reef six miles long was developed, the depth on the reef varying generally from 11½ to 18 feet, but on the western end the depth found was only 8 feet. Deep water is found very close to this reef on the north side. It is recommended in the report of Acting Master Platt that vessels should not pass within the 10-fathom curve on the north side of the Quicksands, as marked on the chart of this vicinity. On the extreme end of the Quicksands the soundings made this season show that there is a large shoal with as little as 6 feet of water on it. The position of Rebecca Shoal, to the westward of the Marquesas, was carefully determined by help of means already described; and as the expedients used favor convictions in regard to accuracy, the position so ascertained will be adopted, though somewhat different from the one heretofore assigned. Isaac Shoal, near the Rebecca, was also carefully sounded and determined in position.

Currents in the vicinity of the Marquesas were observed at six stations by the hydrographic party. The general statistics are as follows:

| | |
|---|---|
| Miles run in sounding | 483 |
| Angles determined | 1,916 |
| Numer of soundings | 14,184 |

The manuscript chart of the vicinity of the Marquesas was turned in at the office in June.

Acting Master Platt was assisted by Sub-Assistant Gershom Bradford and Mr. J. B. Adamson.

Early in June the steamer Bibb returned to Norfolk and, after refitting, was employed in service of which mention was made under the head of Section V. The vessel is now in service near the western end of the Florida Reef.

While the party was at work on the 29th of May, the British ship Coronet was seen to be standing in over the reef and in danger of grounding. She was boarded from the Bibb and was piloted into deep water.

## SECTION VII.

GULF COAST AND SOUNDS OF WESTERN FLORIDA, INCLUDING THE PORTS AND RIVERS. (SKETCH No. 8.)

*Triangulation, topography, and base of verification at Saint Andrew's Bay, Florida.*—Work in this section was resumed towards the close of December, 1869, by Assistant S. C. McCorkle in charge, and Assistant C. T. Iardella, the latter having been detailed for the topographical survey of the shores of Saint Andrew's Bay. The schooner Torrey was employed for the accommodation and transportation of the party.

On reaching Saint Andrew's Bay, Mr. McCorkle made a reconnaissance for the purpose of selecting a site for the proposed base, and finally concluded to measure a line upon the outer beach and to transfer the ends to higher ground. The base consisted of two separate lines, not differing greatly in direction. The measurement was made in January, with the four-meter sliding-contact apparatus. The deduced length of the base is $3{,}444^{m}.7$. It connects with the triangulation by means of two lines opened through the woods. In these operations, Mr. McCorkle was assisted by Mr. Iardella.

The triangulation was continued by Assistant McCorkle from the points at which it was suspended last year, and by the close of the season was carried up the east and north arms of Saint Andrew's Bay.

| | |
|---|---|
| Signals erected | 36 |
| Stations occupied | 39 |
| Angles measured | 204 |
| Number of observations | 3,252 |

The shores of Saint Andrew's Bay are generally high and sandy, with numerous live-oak hummocks and innumerable bayous. The depth of water at the head of the arms varies from 3 to 8 fathoms.

The topographical survey of the eastern and northern arms of the bay was executed by Assistant Iardella, during April and part of the month of May. The country is flat and covered with pine wood, and the shores are ridged with sand and shell banks from 3 to 12 feet above high-water mark.

| | |
|---|---|
| Shore line surveyed | 81 miles. |
| Shore of bayous | 81 miles. |
| Area surveyed | 63 sq. miles. |

## SECTION VIII.

GULF COAST AND BAYS OF ALABAMA AND THE SOUNDS OF MISSISSIPPI AND OF LOUISIANA TO VERMILION BAY, INCLUDING THE PORTS AND RIVERS. (SKETCH No. 9.)

*Hydrography of Lake Borgne, Louisiana.*—The vessel intended for this service was dispatched by Assistant F. P. Webber, from New Orleans on the 15th of January, but struck on a sunken snag in beating through Pass à l'Outre, and sunk in two hours, during which time the vessel was got to the shore. All the property was saved excepting part of the provisions. As soon as possible, Mr. Webber had the Varina raised and refitted. On the 5th of February the party was again under way, and soon after commenced work in Lake Borgne. Few of the points determined before the war could be found. In order to replace them Assistant Webber started at a well-ascertained line, (joining Fort Wood flag-staff with East Rigolets light,) and with the theodolite determined the positions of five high scaffold signals which had been set up by the party under his direction. Intermediate points were also determined for use in the soundings.

Between the 9th of March and the 1st of June, Lake Borgne was sounded, and also the Rigolets, Chef Menteur, and East and West Pearl River, to their junction; Lake Catharine was sounded, and the eastern part of Lake Pontchartrain, or as far westward as the line joining Point L'Herbe and Bonfouca Point.

In summing up the general results of this work, the following remarks are made in the report of Assistant Webber: "The depth of water in Lake Borgne is from 8 to 12 feet, the bottom mostly sticky. There is a shoal a mile and a half wide, with only 6½ feet at mean low water, at the eastern entrance to the Rigolets. At the western end, where it enters Lake Pontchartrain, there is also a large shoal, having only 6 feet at mean low water. The proper channel across this shoal is indicated by soft bottom."

"Although the mean rise and fall of the tide is only one foot, the depth of water varies according to the direction and strength of the wind; southerly and easterly winds sometimes forcing the Gulf water into the lakes and causing a rise of two or three feet. Northerly and westerly winds make a corresponding decrease in depth. In July and August, the water-level is generally from one to two feet higher than during the winter."

Sub-Assistant F. D. Granger rendered effective service in this work. He is now in charge of a hydrographic party in Section IX.

The following is a summary of statistics of the work done in Lake Borgne:

| | |
|---|---|
| Miles run in sounding | 959 |
| Angles measured | 4,042 |
| Casts of the lead | 71,537 |

At a tidal station established by the party near the East Rigolets light, observations were recorded hourly from the 9th of March until the close of the working season.

During the summer and autumn the party was employed in Section I. Assistant Webber, with his aid, Mr. Andrew Braid, is now on duty in Section V.

*Triangulation and topography of Isle au Breton Sound, Louisiana.*—The triangulation and plane-table survey of Isle au Breton Sound, and of the Mississippi River, were resumed by Assistant C. H. Boyd early in the season, but owing to delay in completing the repairs to the schooner James Hall, assigned for the transportation of the party, and to the loss of one and damage to another boat during a severe gale encountered in the Gulf while bound to the site of work, field operations were not commenced until the 21st of February. Between that date and the end of May, the triangulation along the west side of the sound was extended from last year's limits northward until it joined the work previously done. Two plane-table sheets were completed, making the topography continuous with former work. The triangulation of the Mississippi River was carried up from the station Coquille to Grand Prairie. A plane-table sheet of the river banks below the forts was finished, and another, including Forts Morgan and Jackson and the route of the proposed ship-canal. While the schooner was being laid up, an examination was made of the condition of the trigonometrical stations established in the vicinity of New Orleans, in 1858.

In these operations, Mr. Boyd was aided by Mr. J. N. McClintock. Mr. W. E. Boyd, recorder, and Mr. Frank Morgan, pilot, assisted in the work.

The following statistics show the progress made:

Triangulation:

| | |
|---|---|
| Signals erected | 17 |
| Stations occupied | 14 |
| Angles measured | 76 |
| Number of observations | 1,338 |

Topography:

| | |
|---|---|
| Miles of shore-line | 240 |
| Levee | 20 |
| Road | 11 |
| Area in square miles | 45 |

Assistant Boyd passed the working season at the North in Section I, and has now resumed duty on the shores of the Mississippi.

*Special hydrographic service in the West Indies.*—In June, 1870, the West India and Panama Telegraph Company's fleet arrived at Kingston, Jamaica, with sub-marine cables intended to join the principal islands of the West Indies. H. M. S. Vestal had been detailed by the British Government to assist the company. The courtesy due from our Government was recognized by the Honorable Secretary of the Navy, in the dispatch of the United States steamer Yantic to aid Sir Charles Bright, chief engineer of the company, as far as possible in his undertakings. In the same spirit further co-operation was tendered in the assignment of Assistant J. S. Bradford to act, if needful, as navigator of the telegraph fleet. This was done on the suggestion of the president of the International Ocean Telegraph Company, General W. F. Smith. By previous appointment Mr. Bradford reported to Sir Charles Bright at Kingston, and accompanied the expedition in the cable-ship Suffolk. The line on the south coast of Cuba, from Batabano to Santiago de Cuba, was successfully laid in the latter part of July; but many faults, due to the nature of the bottom, occupied the greater part of the month of August, for perfecting the telegraph circuit through the cable. In the manufactory the cables had been tested at a temperature of 78°, which was supposed to be higher than the ultimate temperature of the lines when submerged in the West India waters. It may be so in the deeper waters of the Caribbean Sea, but while the cable was taking its place in the shallow bay near the Isle of Pines, Mr. Bradford found a temperature at the bottom of 85½°, and everywhere along that part of the course temperatures above 80°. The highest temperature was found in seventeen fathoms off the north point of the Great Bank of Jardinillos. Instruments, intended for the use of Assistant Bradford in deep-sea observations, had been provided by Sir Charles Bright, but remained on board of the steamer Yantic. That vessel, when the telegraph fleet reached Kingston, was sounding for the line between Jamaica and Saint Thomas, and left Santiago de Cuba before the arrival of Mr. Bradford at that point. A short time after the Yantic received special orders, and having accomplished the part assigned in the preliminary arrangements of Sir Charles Bright, sailed for Samana Bay, without opportunity to transfer the deep-sea instruments to another vessel.

While he was associated with the cable fleet, Mr. Bradford made for the chief engineer of the telegraph company two large charts of the coast of Cuba and Jamaica, and corrected many inaccuracies in the published charts. Many of the Cays in the labyrinth traversed by the telegraph line between Batabano and Cienfuegos had been wrongly marked in position; and the shore-line of the south side of Cuba, from Point San Juan to Cape Cruz, was found to be exceedingly erroneous.

Assistant Bradford notes the great depth of water between Cuba and Jamaica, and the abruptness of descent from the shore of the first-named island. On the line going due south, and about forty miles from Santiago de Cuba, the depth is 1,750 fathoms, and probably greater depths can be found between the two great islands named. Across this deep-sea chasm Sir Charles Bright successfully laid a cable joining Santiago de Cuba with a station in Holland Bay, or, as marked on the charts, Plantain Garden Harbor, on the northeast side of Jamaica. A third cable was to pass from Kingston to Colon, (Aspinwall,) a point on the south shore of the Caribbean Sea. As the northeast trade-winds blow there with considerable force, it was with due foresight decided to take the cable to Colon, and to submerge it while passing northward, the vessel then being more readily stopped, in case of a break or fault. Assistant Bradford, on board of the Vestal, which was the leading vessel in the absence of the Yantic, accompanied the expedition to Colon, and took part in making observations for latitude and longitude. The Vestal not being provided with any special means for dredging or for procuring deep-sea temperatures, Mr. Bradford took passage at that port on the 20th of October for New York, and reported at Washington, after an absence of five months. He was soon after assigned to regular hydrographic duty, in Section VIII, descriptions of which will be given in my next annual report.

## SECTION X.

COAST OF CALIFORNIA, INCLUDING THE BAYS, HARBORS, AND RIVERS. (SKETCHES Nos. 10 AND 11.)

*Triangulation of the Santa Barbara Channel, California.*—At the date of my last report Assistant George Davidson was in the field determining latitude and azimuth and connecting a point in the triangulation of the Santa Barbara Channel with San Francisco for longitude by telegraphic observations. For this purpose he occupied the station Buena Vista in the city of Los Angeles, and joined it with the main line of telegraph which passes to San Francisco.

At station Santa Barbara he observed 170 additional measures of horizontal angles with the 18-inch theodolite; 41 measures for azimuth upon $\delta$ and $\lambda$ Ursæ Minoris and 51 Cephei, and 126 transits of stars, with the Davidson meridian-instrument.

From that station and Hills, the positions and elevations of seven peaks of the Santa Barbara Mountains were determined. Thirty-two double altitudes upon 15 objects were recorded from readings with the three-inch theodolite No. 3104.

Station Hills was occupied by the aid, Mr. S. R. Throckmorton, jr., with the 8-inch Gambey theodolite No. 44, to determine the positions of the mountains and the azimuth mark. Before leaving that vicinity Mr. Davidson furnished for the trustees of the town of Santa Barbara true meridian marks from the station Santa Barbara, as means of reference for the county surveys. Station Pelican was examined and identified, and the azimuths determined there were connected with the main triangulation.

At station San Buenaventura Assistant Davidson made 278 observations for latitude with the zenith telescope No. 1, upon 91 stars in 39 pairs and triplets. Of this series 6 pairs were also observed at Santa Barbara. With the meridian instrument, 174 transits were recorded in observing 60 stars; 297 measures of horizontal angles were made with the 18-inch theodolite No. 4; and 497 measures for azimuth upon $\lambda$ Ursæ Minoris and 51 Cephei. The azimuth mark was connected directly with the main station, Santa Barbara.

Assistant Davidson, in making azimuth observations, noticed sensible changes of level and also twisting of the point of bluff on which the triangulation station was placed in 1857. His remarks on the changes are given in the Appendix. At San Buenaventura a station was selected on the mountain-flank, from which observations could be made upon the island of Santa Barbara. The height of station San Buenaventura was determined, and 28 double altitudes were observed upon 13 objects with the 3-inch theodolite for the approximate elevation of the adjacent triangulation stations.

At Dominguez Hill station in the Los Angeles Plains Mr. Davidson observed for azimuth, and instituted a series of latitude observations with zenith telescope No. 1 and the Davidson meridian instrument upon the same pairs of stars, in order to compare the capabilities of the two instruments. With the zenith telescope 173 observations were made on 74 stars in 34 pairs and triplets; and with the meridian instrument 134 observations upon the same stars. Notes were made here, as at the other stations, upon the relative magnitudes of the stars of the latitude lists. With the meridian instrument 292 observations were made upon $\alpha$ Ursæ Minoris near western elongation for the value of the micrometer-screw; 113 transits were observed upon 34 stars; 460 measures for azimuth upon $\alpha$ Ursæ Minoris near elongation with the 18-inch theodolite No. 4; 195 measures of horizontal angles were made upon 7 main and 2 secondary objects, and 13 mountain-peaks; and 32 double altitudes were observed with the 3-inch theodolite upon 22 objects, including the peaks of Catalina Island. The peaks lying between the great plains of Los Angeles and the Great Desert reach 9,940 feet above the sea. Station Buena Vista, in Los Angeles, was connected with the main triangulation, and for longitude with San Francisco by telegraphic observations. At West Beach station a signal was erected, the station was occupied and connected with Buena Vista by observations with the 10-inch theodolite No. 37. Fifteen objects were observed upon and 15 angles measured, with 129 observations. Preliminary observations were obtained upon Santa Barbara Island for its relative position. Exclusive of a line run with the spirit level from low water to the station, 243 feet above the sea, 8 double altitudes were observed upon 4 objects for the elevation. Southwest Base station was visited and measures were established for its easy recognition on the plains.

At Buena Vista the 10-inch theodolite was used in measuring 12 angles with 97 repetitions. By permission of the city councils of Los Angeles, a brick pier was set up at that station for the transit instrument.

*Astronomical observations.*—At Buena Vista, in Los Angeles, Assistant Davidson obtained permission from the president of the California State Telegraph Company, George H. Mumford, esq., to connect the observatory by a loop with the telegraph line. After adjusting the meridian instrument the station was left in charge of Mr. Throckmorton, while Mr. Davidson repaired to San Francisco, where he received upon the chronograph the transits of Buena Vista, observing the same stars with the transit No. 3, and recording them on the same chronograph.

These interchanges were successful upon four nights; 44 transits of 28 stars were registered at San Francisco, and 35 transits of Buena Vista observations upon 25 stars, of which 26 observations were upon 35 stars of the same series. At Buena Vista Mr. Throckmorton observed, in addition to interchanges, 53 transits of 35 stars; and at San Francisco Mr. Davidson observed 30 transits of 10 stars. Subsequently, the two observers recorded at San Francisco 27 transits for personal equation.

At San Buenaventura Assistant Davidson observed two occultations of stars by the moon; and at station Santa Barbara, November 13, 1869, assisted by Messrs. Throckmorton and Harford and by Mrs. Davidson, he recorded the flight of 556 meteors, and furnished the particulars in a special report. The same observers noted the meteors of November 13, 1870, at San Francisco, recording the times upon the chronograph register. These interesting details were transmitted to Professor Newton, of Yale College.

*Magnetic observations.*—The usual series of magnetic observations were made at stations Santa Barbara, San Buenaventura, and Dominguez Hill. For absolute magnetic declination, Assistant Davidson and Mr. Throckmorton made 430 observations; for horizontal intensity, 330 observations, using magnetic theodolite No. 5. With the dip-circle No. 11, 324 observations were made, using three needles, each in three positions of the axles.

Twenty-five volumes, containing duplicates of the records of Assistant Davidson's work on the Santa Barbara Channel, have been received at the office. His observations at other localities within the past year are comprised in forty-four volumes, which are yet in hand for duplication.

*Topography and tertiary triangulation of the Santa Barbara Channel.*—During the early part of the winter Sub-Assistant A. W. Chase was engaged in computations and in inking sheets of his previous work. Duplicates of the reductions have been received at the office.

Later in the season Mr. Chase commenced the topography and necessary tertiary triangulation near San Pedro Bay, working westward from the limits of the plane-table survey of 1854. His survey embraces the coast from Point Fermin to Point Vincente, a bold rocky shore backed by a mountain ridge which attains an elevation of 1,478 feet. The crest-line of this ridge is shown on the topographical sheet, which is filled with heavy contouring throughout. The statistics are:

| | |
|---|---|
| Ocean coast-line surveyed | 8 miles. |
| Area, (square miles) | 12 |

San Pedro Mountain is a bold landmark for that part of the Santa Barbara Channel. It exhibits a series of four or five well-defined old sea-benches upon its flanks. These are represented on the topographical sheet.

The topography was based upon a tertiary triangulation made by Mr. Chase, and connected with the Santa Barbara scheme of triangulation. He determined 25 stations by 144 measures with a 6-inch repeating theodolite. The duplicates and computations of this work were kept up and plotted as the plane-table survey advanced. The original inked sheet has been received at the office. Tracings were previously furnished to the light-house engineer on the Pacific coast.

At station San Pedro Mr. Chase measured the vertical angles of the mountain-peaks on Catalina Island and of other objects with the 3-inch theodolite; and also horizontal angles to determine the position of Santa Barbara Island.

Regular meteorological observations were registered while the party was in the field.

Sub-Assistant Chase was aided by Mr. Max Lipowitz. As soon as the season would permit work to the northward, this party was transferred to Crescent City.

Assistant W. E. Greenwell completed in the course of the winter the plane-table sheets and duplicates of his observations, with descriptions of the signals used in his previous work. These have been received at the office. At the opening of spring he continued the topography along the coast of the Santa Barbara Channel, from El Rincon to San Buenaventura, and there joined with the work done in 1854. His survey includes also the mouth of the river, and the vicinity of the town of San Buenaventura. From Point Gorda to San Buenaventura, a distance of 12 miles, the topography is mountainous, rugged, without settlements, and destitute of wood or water fit for use. Several triangulation stations, established by Assistant Greenwell for this work, served also to furnish the trustees of the town of San Buenaventura with points for a meridian line. From this vicinity the party was transferred to the west of Santa Barbara, and resumed the plane-table survey at the limits reached by Assistant Harrison in 1852. The work was continued toward Point Conception, as far as the Goleta. A tertiary triangulation, previously executed by Mr. Greenwell, served as a basis for this survey. At the date of his report the topography had been extended nearly to station Pelican, and embraced a resurvey of the town of Santa Barbara, to include the improvements since 1852. There, the secondary astronomical station occupied by Assistant Davidson in 1852 was re-established, and connected with the regular scheme of triangulation of the Santa Barbara Channel, and with the main astronomical station occupied by Mr. Davidson in 1869.

The topographical work of the party this season fills four sheets on a scale of $\frac{1}{10000}$, the projections of which were furnished from the office. The statistics of the topography are:

| | |
|---|---|
| Ocean shore-line | 33 miles. |
| Bluff outline | 12 miles. |
| Rivers and streams | 37 miles. |
| Roads | 89 miles. |
| Area of topography, (square miles) | 47½ |

The greatest elevation represented by the topography is 1,258 feet. The statistics of the triangulation are:

| | |
|---|---|
| Signals erected | 8 |
| Stations occupied | 6 |
| Objects observed | 16 |
| Number of observations | 458 |

The 8-inch theodolite No. 44 was used in the measurement of horizontal angles.

Assistant Greenwell was aided throughout the year by Mr. Stehman Forney.

*Hydrography of the Santa Barbara Channel and of San Buenaventura Harbor, California.*—In order to determine what changes had taken place in the anchorage at San Buenaventura, as indicated by the surveys of 1856 and 1869, Assistant Greenwell made soundings there within an area of 7 square miles, measuring 1,193 angles for position, and taking 3,558 casts with the lead. It is thought that in great freshets the river San Buenaventura brings down large quantities of material.

The reduction of the hydrographic work done by Assistant Cordell in 1869 in the Santa Barbara Channel has fully developed a hitherto unknown danger, the rock which lies 12 miles westward of Santa Barbara and one mile off shore, having only 15 feet of water upon it, while the sounding-line gives 7 fathoms inside of the rock.

*Hydrography near Piedras Blancas, California.*—In November, 1869, Assistant Cordell was instructed to search for the Harlech Castle Rock, which was reported to be three miles off shore, and five miles north of Piedras Blancas. It was said to have 14 feet upon it and 25 fathoms inside of it. He was successful in the search, the wrecked vessel's mast being at the time above water. On account of the lateness of the season, this examination was partial, but Mr. Cordell established the position of the rock. It is bare at low water, and is 400 yards inside of the kelp line, and inside of the line joining the adjacent points north and south of it. The rock is out of the track of vessels. The depth is 10 fathoms one mile outside of it, and but 3 or 4 fathoms inside.

This was the last duty performed afloat by Assistant Cordell. He returned to San Francisco and had in hand the plotting of soundings which had been made in the course of the season, when his labors were stopped by sudden death, on the 25th of January.

*Hydrographic reductions.*—Sub-Assistant George Farquhar, who was placed temporarily in charge of the hydrographic party after the death of Assistant Cordell, has plotted all the work done in 1869 in the Santa Barbara Channel, and inked and traced 8 sheets of in-shore hydrography upon a scale of $\frac{1}{10000}$, and one sheet of off-shore hydrography on a scale of $\frac{1}{100000}$. These charts have all reached the office in Washington. The original hydrographic records have been partly duplicated. At an interval in the office-work, Mr. Farquhar determined the position and extent of the wharf of the Central Pacific Railroad Company, from Oakland Point to the ship-channel lying on the east side of Yerba Buena Island.

*Buoys in the entrance and approaches to San Francisco Bay.*—Assistant Davidson in the course of the season called my attention to the importance of buoys for the Presidio Shoal in the entrance to San Francisco, and also for a mark upon the west side of the Boneta Channel, abreast of the Boneta light. This channel affords a depth of 8½ fathoms for entering or leaving San Francisco Bay. Acting upon these suggestions, the Light-house Board placed the buoys as recommended. The positions of these aids to navigation were subsequently determined by Sub-Assistant Farquhar and Mr. Throckmorton, aid in the party of Assistant Davidson.

*Yerba Buena Channel, San Francisco Bay, California.*—Upon becoming familiar with the bay of San Francisco and its approaches by land and sea, one might easily be impressed with the thought that the future welfare of California and of the region adjacent must ever be critically involved in any and all projects that contemplate changes in the physical order and regimen of this magnificent basin and its outlet. It is estimated that two-thirds of the drainage of the State of California finds its way into San Francisco Bay, and in equal measure, at least, we should estimate and expect to provide for the conveyance of trade; for, although railways have modified the old rules of commercial development in many particulars, they are all pathways to the ocean, and must hasten the concentration of wealth and population at the best havens upon the sea-board.

At the time of my visit, in July last, the pile-wharf of the Central Railway projected about 3,711 yards into San Francisco Bay, and the company were petitioning for permission to cross the Yerba Channel to the shore of Yerba Buena Island, a further distance of 1,089 yards. An encroachment so extensive naturally excited alarm among public-spirited individuals, and seemed to require a careful inquiry into the probable effects of the proposed structure. I therefore directed Assistant Henry Mitchell, who has charge of the division of physical hydrography, to make a series of observations upon the volumes of water passing through the channels in this vicinity, and the comparative work executed by them. In his report, Appendix No. 18, he sums up the results in the following words:

"It appears from these data that the complete closure of the Yerba Channel would augment the velocity in the main channel only 12 per cent. If we confine our attention to the portion of the present railroad-pier which serves as a bridge only—that is to say, if we take the present wharf, exclusive of the portion containing slips and ferry-berths, we find from our observations that the reduction of velocity caused by the piles is 15 per cent., from which we may safely conclude that if the bridge were to be extended, with similar construction, to the island, the loss of passing volume would be less than four million cubic yards, and the augmentation of the velocity in the main channel only 2½ per cent."

The southern part of San Francisco Bay receives but little land-water. Its small feeders, even when swelled to torrents in the rainy season, do not cause any considerable flood as low down as the neighborhood under consideration, so that the proposed open bridge would not operate as a dam to any serious disadvantage. I would not be understood to say that the bay is subject to no rise in the rainy season, but that the rise which occasionally occurs does not come from the inflows above (southward of) the site of the proposed structure.

If the open bridge should be built, I see no reason to apprehend that the augmentation of flow through the main channel will at any time be so great as to increase sensibly the present inconveniences of the anchorage, either directly by causing vessels to part their chains, or indirectly by scouring away the present patches of excellent holding-ground. That the structure will close to future use a navigable avenue, is an objection that must be weighed by the commercial public in the balance with the immediate advantages of the railway extension, and, as far as I can see, this is the only question that need be entertained, since no serious disturbance of the physical order, affecting other portions of the bay, can be predicted.

*Middle time.*—One of the useful results of Mr. Mitchell's visit to the Pacific coast, is an improvement in the form of the current-tables for those ports where the diurnal inequalities of the tides are large. He suggests that the "*middle time of flood*" and the "*middle time of ebb*" should be made the principal elements, because least subject to variation, and because most valuable to the navigator, who desires most of all, in approaching a port, to know at what time he is likely to find an ebb-current too strong to be stemmed or a flood-current strong enough to carry him over the bar or past other dangers.

The diurnal inequalities in the intervals of high water have the opposite sign from those of low water, except at those dates when the diurnal tide-wave is small and about to shift its relative position to the semi-diurnal tide; an intermediate phenomenon, therefore, like maximum flood or ebb-current, would usually remain unaffected except at the inlets of great lagoons where the tides and currents are not synchronous.

The outflows of rivers, and even the movements due to winds, may be regarded as uniform during a single tide, and without effect upon the time of maximum velocity. The "middle time," computed from all the observations of an entire flood or ebb, is preferable to the selection of the highest velocity recorded, because any single observation may be affected by the yawing of the vessel or by some other accident.

The great labor required in arranging tables from the voluminous observations in the archives of the Coast Survey has delayed Mr. Mitchell's report on the subject.

*Astronomical observations at Point Arena and San Francisco, California.*—To connect the triangulation near Point Arena, which now includes, as one of the stations, the new light-house there, with San Francisco, for longitude, Assistant Davidson transported 19 chronometers from the Washington Square observatory to Arena Cove. At the San Francisco station, transit No. 3 was used with the Kessel's clock and a Hipp chronograph; at Arena the Davidson meridian-instrument was used with a Frodsham's break-circuit chronometer and the Hipp chronograph. The time observations at both places embraced 156 transits of 73 stars. At Arena, latitude observations were made with the meridian-instrument on 11 pairs of stars during one night. A meridian-mark was set there for the subsequent uses of Sub-Assistant Sengteller.

*Magnetic observations.*—For the determination of the magnetic declination at Arena Village, with the theodolite magnetometer No. 5, 63 observations were recorded on two days, and others were made for azimuth. The station was connected with the triangulation. Five volumes, containing the records of Mr. Davidson at this station, have been received at the office.

Before returning to San Francisco, Assistant Davidson made a general examination of the coast from Russian River to the northward of Point Arena. In this service he was accompanied by his aid, Mr. Throckmorton.

*Topography and triangulation at Point Arena, California.*—Sub-Assistant Louis A. Sengteller organized a party for the topography and necessary triangulation at Point Arena, early in the winter of 1869–'70, commencing at a point about 7 miles south of the light. From thence the work was extended to the northward. The means available for this service were limited, the season was late, and it proved to be rainy.

The topographical work done by this party is included in two sheets. These represent the small shipping cove to the southward of Arena, and the coast to a point 9 miles northward of the light-house. Some heavy country is embraced, partly covered with timber, and a varying coast-line of bold bluffs and sand-dunes. The highest point shown by the topography is 820 feet. In prosecuting the plane-table survey, attention was incidentally given to the lines of plateaux, exhibiting the features of old sea-levels. The statistics of the work are:

| | |
|---|---|
| Ocean shore-line surveyed | 21 miles. |
| Shore-line of streams and ponds | 15 miles. |
| Roads and trails | 32½ miles. |
| Area, (square miles) | 15 |

The survey includes the village of Arena.

For the triangulation, Mr. Sengteller chained a base on the Point Arena plateau, and from it extended a series of triangles north and south to embrace also the crest-line of the sea-coast mountains. This scheme was arranged so as to connect hereafter with the secondary astronomical stations of 1853, occupied by Assistant Davidson, at Haven's Anchorage and Mendocino Bay. At the latter station Mr. Sengteller found almost intact the original markings of the station. The following are the statistics of this triangulation:

| | |
|---|---|
| Signals erected | 15 |
| Stations occupied | 14 |
| Angles measured | 89 |
| Number of observations | 1,527 |
| Signals determined | 21 |

The highest point occupied in the triangulation is 2,011 feet above sea-level. After connecting the work with the meridian-marks established by Assistant Davidson at Arena, Mr. Sengteller made a reconnaissance towards Mendocino Bay. He also erected the astronomical pier at Arena; and in May accompanied Mr. Davidson along the coast for selecting stations to extend the triangulation. The records of work done near Point Arena have been duplicated and computed, and the topographical sheets have been inked. During part of the season Sub-Assistant Sengteller was aided by Mr. H. Vincent, and for the remainder by Mr. Charles Schenk.

When about to transfer his party to the southern coast for work this winter, the house in which Mr. Sengteller had placed his topographical sheets and instruments was burned, and subsequently the vessel in which they were shipped was wrecked, but he nevertheless brought all in safety to San Francisco.

*Topography and triangulation of Humboldt Bay and vicinity.*—Assistant Augustus F. Rodgers, after inking and tracing the sheets of the previous year, and duplicating and computing the work of triangulation, resumed field duty on Humboldt Bay, at the northern limit of the previous season's work. He there measured a base of over 2,000 meters with the auxiliary base apparatus of the survey, and from the resulting length he recomputed the previous triangulation and made his projections for the topographical sheets. Observations for azimuth were made on Polaris at elongation at the astronomical station which was occupied by Assistant Davidson in 1869, and this Mr. Rodgers connected with his triangulation. The topography of the season is comprised on six sheets, by which the survey was extended from Table Bluff to Gihon's Bluff. A supplementary sheet shows the changes observed at the mouth of Eel River. The nature of the country surveyed is diversified. Humboldt Bay is fringed by a large area of marshy flats cut up by extensive sloughs. North of it the ocean beach is in part sand-dune, but from Little River to Gihon's Bluff, north of Rocky Point, it is bold, and, being mostly covered with heavy forests to the edge of the bluffs, it is inaccessible with the plane-table. The statistics of the topography are—

| | |
|---|---|
| Shore-line of bay and ocean | 88 miles. |
| Sloughs and creeks | 103 miles. |
| Roads | 31 miles. |
| Area, (square miles) | 59 |

The plane-table sheets of Assistant Rodgers show elevations as great as 600 feet.

The shore-line of the ocean beach and of Humboldt Bay and other needful data were furnished to Sub-Assistant Farquhar for the hydrography of the bay and approaches.

The triangulation was extended northward to embrace determinations of the position of Redding's Rock, which lies off-shore several miles north of Rocky Point. The dense forests and the general level of the country bordering the sea prevent the development of triangulation in this neighborhood.

The statistics are:

| | |
|---|---|
| Signals erected | 54 |
| Stations occupied | 44 |
| Objects observed on | 46 |
| Number of observations | 4,550 |

During part of the season, Assistant Rodgers prosecuted the field-work with a detached party, one plane-table being assigned to Mr. E. F. Dickins, who acted as aid during the season.

Before leaving the vicinity, Mr. Rodgers incidentally made a hydrographic examination of the entrance and bar of Humboldt Bay. The results will be used for comparison with soundings made by the hydrographic party of Sub-Assistant Farquhar.

*Hydrography of Humboldt Bay and approaches.*—In October, 1869, Sub-Assistant George Farquhar was instructed to organize a party and make a hydrographic survey of Humboldt Bay and the approaches. Notwithstanding the bad weather which marked the season, he made a successful examination. The shore-line and the positions of the signals were furnished by Assistant Rodgers, and the sounding-lines run were plotted as the work advanced. Four sheets have been filled, embracing the approaches as far south as Table Bluff. The examination shows that changes are continually taking place at the entrance and on the bar. Tidal observations were made at Eureka through one entire lunation. The statistics of the work are:

| | |
|---|---|
| Miles run in sounding | 310 |
| Angles measured | 3,276 |
| Casts of the lead | 12,636 |

Sub-Assistant Farquhar, after plotting the work and duplicating the sounding-book, forwarded his records to the office. He was aided by Mr. F. Westdahl. Mr. Farquhar is now engaged in a detailed examination of Blossom Rock, in San Francisco Bay. In the course of the season he made projections for the hydrographic survey of the approaches to Crescent City and Cape Orford.

*Topography and tertiary triangulation north of Crescent City, California.*—Sub-Assistant A. W. Chase transferred his party from San Pedro to Crescent City in April, and continued the topography and triangulation from the limits of his last year's work. North of Lake Earl he measured a base of 900 meters, with the subsidiary base apparatus, and carried the triangulation along the coast of California and Oregon to the westward of Chetko River, resting on the Northwest Seal Rock of the Crescent City Reef. At the request of the United States surveyor-general for California, Sherman Day, esq., Mr. Chase connected the north boundary of the State as marked by the United States land-office survey, with the triangulation, and furnished a tracing of the shore-line from Crescent City northward, to include the forty-second parallel. For the computation of the L. M. Z's he observed a preliminary azimuth by means of Polaris at elongation. In the topography the shores of Lake Earl are included. Fours sheets were filled, and the work embraces elevations of 1,300 feet. The computation of the triangulation was kept up in duplicate as the field-work advanced. The statistics of the triangulation are:

| | |
|---|---|
| Signals erected | 63 |
| Stations occupied | 59 |
| Angles measured | 326 |
| Number of observations | 4,193 |

The topography includes:

| | |
|---|---|
| Ocean shore-line | 24 miles. |
| Shore-line of lakes and rivers | 31 miles. |
| Area, of topography, (square miles) | 23 |

The ground-features are much varied; in part a line of low confused sand-dunes backed by dense forests; in other places high, rocky, broken bluff with table-land between the coast and the hills, which are in part timbered; toward the westward the coast assumes a much wilder aspect. Mr. Chase while in the vicinity made search for the astronomical station which had been occupied by Assistant Davidson in 1853, at Crescent City. The bluff had washed away in the interval, but by the angles of reference its site was identified and transferred to firm ground.

A meteorological journal was kept by the party while in the field. During part of the season Sub-Assistant Chase was aided by Mr. Max Lipowitz, and subsequently by Mr. Uhlig. At the date of his report he had disbanded his party and was engaged in inking his sheets and computing the L. M. Z's preparatory to resuming work on the Santa Barbara Channel.

The shore-line traced north of Crescent City gives a good basis for the development of the hydrography off-shore, and through the dangerous reef off Point Saint George.

*Tidal observations.*—The self-registering tide-gauge at San Diego has been kept running by Mr. William Knapp and that at Fort Point by Mr. F. P. Thompson. Each of these observers has, also, furnished a good series of meteorological observations, and tabulated the readings of high and low waters from the tide-rolls. Scales graduated on glass were supplied from the office for that purpose.

My acknowledgments are due for the efficient supervision of Major G. H. Elliot, United States Engineers, of the operations for several years at these stations, reference to which has been made in previous annual reports. Late in March last, the care of the stations was transferred by that officer to Major G. H. Mendell, of the United States Engineers, and thus the continuity of the series of observations for ultimate purposes is properly assured.

## SECTION XI.

### COAST OF OREGON AND OF WASHINGTON TERRITORY, INCLUDING THE INTERIOR BAYS, PORTS, AND RIVERS. (SKETCH No. 12.)

*Topography of the shores of the Columbia River.*—Assistant Cleveland Rockwell continued the plane-table survey on the north bank of the Columbia until the end of November, 1869, and completed the details between Chinook Point and Gray's Bay. The country being almost inaccessible on the north side of the river, the work of contouring was very difficult.

During the winter of 1869, Mr. Rockwell inked and traced the topographical sheets of the previous season. These sheets have been received at the office. He projected three sheets for the work of the year just closed, and in May re-organized his party and resumed the topography of the shores and islands of the Columbia, basing it on the triangulation which was made by Assistant Cutts in 1852. In the interval some of the marks of the tertiary stations had been hidden by a growth of timber, but nearly all of them were found.

The work of the season, which closed in November last, includes both banks of the river and the numerous low, marshy islands in it as far up as Cathlamet Point and Three Tree Point, where the river contracts to a width of two miles. The widest part, from the head of Gray's Bay to the south shore, is nearly nine miles across. The mud flats of Gray's Bay, and the flats, marshy islands, and sloughs on the southern side of the river, were mapped carefully, and pains were taken to delineate the low-water lines. The statistics of the topography are:

| | |
|---|---|
| Main shores of river | 50¾ miles. |
| Shore-line of islands | 114 miles. |
| Shore-line of creeks | 52¼ miles. |
| Area, (square miles) | 49 |

Assistant Rockwell used for transportation the schooner Humboldt. Early in August Mr. George H. Wilson joined him as aid, and is yet attached to the party.

The shores of the Columbia River are rocky and high, densely covered with large timber and thick undergrowth, and impenetrable for any distance with the plane-table. Some points on the crest of the ridges nearest to the river shores have been approximately determined in position, and the general characteristics of the topography have been sketched in.

*Magnetic observations.*—While on a tour of inspection along the northern coast, Assistant George Davidson determined the magnetic declination at Astoria and at Portland, with the theodolite magnetometer No. 5. The number of observations recorded for time, azimuth, and declination, is 244. Duplicates of the records have been received at the office. He was aided in this service by Mr. S. R. Throckmorton, jr.

*Topography of Port Discovery, Washington Territory.*—Under many disadvantages arising from bad weather, the plane-table survey of the shores of Port Discovery was continued by Assistant J. S. Lawson until the middle of October, in 1869. At that date the entire shore-line had been traced, though the dense fog that prevailed in the Strait of Fuca had steadily encroached, and finally enveloped the site of work. Further operations being thus prevented, the brig Fauntleroy was sent to Olympia to be laid up for the winter, but owing to a long-continued calm she did not reach that port until the 25th of October, although towed most of the distance by her crew in a whale-boat. After securing the vessel and discharging the crew, Assistant Lawson and the aid, Mr. J. J. Gilbert, took up and completed the office-work of the season. Reference will be made further on to the resumption of work in this vicinity.

*Triangulation and topography of Puget Sound and of the Strait of Fuca, Washington Territory.*—In February, Mr. Lawson made a reconnaissance for connecting the solar eclipse station of July 18, 1860, with the triangulation of Puget Sound. He found the station, and selected others to be occupied later in the season. In this examination he fortunately identified the astronomical station which was occupied in 1841 by the United States Exploring Expedition, under Lieutenant (now Rear-Admiral) Charles Wilkes, and connected it with the coast triangulation. In connecting the solar eclipse station, four miles of avenues through heavy timber were opened by the party. The triangulation of the Strait of Fuca in the vicinity of Dungeness was carried forward, to include Washington Harbor, and was connected with the work of 1855. After the completion of the plane-table work there, the triangulation was extended to the southward of Deception Pass, along the western shores of Whidbey Island. All the records of this work have been turned in, with the abstracts and the computations. The statistics of the triangulation are as follows:

| | |
|---|---|
| Signals erected | 75 |
| Stations occupied | 61 |
| Objects observed on | 686 |
| Angles measured | 330 |
| Number of observations | 13, 621 |

The area covered by the triangulation is 160 square miles. Sixty vertical angles upon four objects were observed from one station of the triangulation; and observations for the position and elevation of Mount Rainier were also made by Assistant Lawson. The country between Washington Harbor and New Dungeness was examined for a base-line of three or four miles in length, but no site was found suitable for measurement. The ground is heavily timbered and covered densely with undergrowth, and the surface is much broken by marshy stretches, broken bluffs, and creeks.

A site for a base of verification for the triangulation which extends through Admiralty Inlet and Puget Sound from the Port Townshend base of 1855, was selected by Assistant Lawson. This line can be readily connected with the triangulation from the solar eclipse station.

In May, Mr. Lawson organized a detached party for topography. The plane-table work, done under his direction by Mr. Gilbert, includes the final sheet of Port Discovery, and on others the shore from thence to New Dungeness, with Washington Harbor, and the mouth of the Dungeness River, where great changes were caused by the severe storm of 1866. The shores of Whidbey Island were mapped from Admiralty Head southward to Lagoon Point, and the shores of Smith's Island and Minor Island, where important changes have taken place. The country surveyed is difficult for the topographer, the shores being bordered by thickly-set timber and brush, growing on moderately level ground. The work was delayed in July and August by smoke from the adjacent burning forests. Statistics of the topographical work are appended:

| | |
|---|---|
| Shore-line surveyed | 43 miles. |
| Lakes and sloughs | 19 miles. |
| Roads | 27 miles. |
| Area of topography, (square miles) | 19 |

A meteorological journal was kept by the party during the working season.

*Hydrography of the Strait of Fuca, Washington Territory.*—Assistant Lawson discovered a dangerous ledge of rocks in the southern entrance to Rosario Strait, having but 3¼ fathoms upon it, with 56 fathoms near it on all sides. On account of the lateness of the season and bad weather, the survey of the vicinity was not completed, but the position and extent of the ledge have been determined. This danger to navigation is in the direct line of vessels through Rosario Strait. Mr. Lawson also sounded to the eastward of Belle Rock and Rosario Strait, but the stormy character of the season interrupted the work. By the courtesy of the collector of customs, Mr. S. Drew, esq., at Olympia, the revenue cutter Lincoln was employed in these examinations, and great interest was manifested by Captain Scammon and by the officers of the cutter in prosecuting the work.

The recommendation that buoys be placed on the Toliva and Itsami Shoals in Puget Sound was met by favorable action in the Light-house Board.

After laying up the brig Fauntleroy at Olympia, the party was disbanded for the winter. Mr. Lawson is now engaged in his computations and other office-work.

*Tidal observations.*—At Astoria, on the coast of Oregon, the excellent series of tidal and meteorological observations have been maintained by Mr. L. Wilson. This station and the permanent ones in Section X are now in charge of Major G. H. Mendell, United States Engineers, who kindly undertook the care of them in March last. For several years they had previously been under the supervision of Major Elliot, of the Engineers, as already stated.

## COAST SURVEY OFFICE.

The organization of the office has remained the same as for several years past, under the charge of Assistant J. E. Hilgard. Its principal operations are recited under the following heads:

*Computing Division.*—The work of this division has been, as heretofore, under the immediate charge of Assistant Charles A. Schott, under whose able direction the progress of the work has been kept up to a very satisfactory standard. In addition to performing the duties of this charge, Mr. Schott made in June magnetic observations at the station in Washington, keeping up the continuity of the series, and in autumn accompanied the party of the Superintendent for observing the solar eclipse of December 22, 1870. His services as an observer at Catania, in Sicily, are noticed in Appendix No. 16.

The adjustment, by the method of least squares, of the primary triangulation on the eastern coast has been completed, and that of the secondary triangulation has been pushed forward as fast as the limited force of computers permitted. The introduction of improved places of stars, from the most recent determinations, for our astronomical latitudes is rapidly advancing. Assistant Schott established the conditional equations of the primary triangulation south of Kent Island, made a revision of the reduction of the transatlantic telegraphic difference of longitude between Greenwich and Cambridge, Massachusetts, commenced the micrometric measures of the photographic images of the solar eclipse observed by him at Springfield, Illinois, 1869, and among other reports submitted the following:

On a preliminary investigation respecting the choice of the localities favorable for observing the next transit of Venus across the sun's disk; on the deflection of the plumb-line in the vicinity of the District of Columbia; a preliminary determination of a spheroid which best represents the astronomical and geodetic measures on the surface covered by the primary triangulation between Calais and Washington.

He also submitted supplementary papers on a former report on determination of time and of azimuths.

The force employed in the division, and the distribution of duties, have been the same as for several years past, Assistant T. W. Werner computing the current triangulations; Dr. G. Rumpf and Mr. E. H. Courtenay making the verifications of the same by comparison with the field-computations, keeping the registers of geographical positions, and making the computations of final adjustment of the triangulation, while Mr. J. Main made the computations of astronomical work. Mr. E. A. Bowser also assisted in the computations during several months.

*Tidal Division.*—The inspection of the tidal and meteorological observations, when received at the office, the correspondence with the observers, the supervision of the computations, and other work relating to tides and tide-gauges, have been kept up by Mr. R. S. Avery, assisted by Mr. A. Gottheil, Mr. J. Downes, and Miss M. Thomas. All data and other information respecting tides, required for office use, for observers, and for the use of field-parties, have also been furnished. The ordinary reductions of the observations, and deduction therefrom of the general results used for charts and other purposes, have been made as soon after the observations were received as practicable.

The tide-tables, or predictions, for 1871, the fifth year of the series, have been computed in this division, and are published. They contain the approximate predicted times and heights of the tides for about twenty of the most important places on our coasts, with tables of constants for finding from them the tides for a great number of other places.

*Hydrographic Division.*—The drawing and verification of hydrographic charts from the original notes of soundings and angles, the verification of charts reduced to the scales of publication, the preparation of sailing-directions and all notes pertaining to navigation, have been, as heretofore, performed in this division of the office, under the immediate direction of Captain C. P. Patterson, inspector of hydrography, by Mr. E. Willenbücher, assisted by Mr. J. Sprandel.

*Drawing Division.*—In the conduct of this branch of the office the assistant in charge has been ably seconded by Mr. W. T. Bright, who has had charge of the details of the division, and has materially assisted in planning the work. The drawings for engraved charts have been made by Mr. A. Lindenkohl, chief draughtsman, and by Messrs. H. Lindenkohl, L. Karcher, and F. Fairfax. Traced copies of maps have been made by W. Fairfax and B. Hooe. Views of headlands and approaches to harbors have been taken during the year by Mr. W. McMurtrie, and were afterward drawn by him for engraving on the charts. Copies of manuscript maps and charts, or portions of such, are frequently furnished, upon request, to other branches of the public service, as well as to private persons; the latter, of course, paying the cost thereof. This is an important form in which the information collected by the Coast Survey becomes available to the public, and a list of the maps so furnished during the year is given in Appendix No. 2. A list of the maps and charts, either wholly drawn during the year, or the work on which has been continued as far as the material on hand permitted, together with the names of the persons engaged upon them, is given in Appendix No. 3.

In addition to the work shown in that table, comprising fifty-three maps and charts worked upon, and eleven completed, the following statement will serve more fully to exhibit the operations of the division:

| | |
|---|---|
| Projects for new charts prepared | 9 |
| Tracings made on special calls | 106 |
| Projections made for field-maps | 37 |
| Projections made on copper for engraved charts | 4 |
| Miscellaneous tracings and diagrams for field and office use | 88 |
| Topographical sheets traced for reduction by photography | 8 |
| Diagram maps of Florida Keys, drawn in duplicate for Land-Office | 53 |

*Engraving Division.*—In this division, under the efficient direction of Assistant E. Hergesheimer, the progress of the work has been well sustained. During the year thirteen charts have been completed, eight new ones have been commenced, and the work on nineteen has been continued, besides the usual amount of miscellaneous additions to the progress-sketches and other plates not specified in the tabulated report, Appendix No. 4.

The reduction of outlines upon the plates with the pantograph has continued to give satisfactory results, and to facilitate and economize the work of the division; while the rouletting of the tints of the usual sections of the bottom has enabled us to publish rapidly a class of charts very desirable and useful, in advance of the more detailed and finished harbor-charts.

During the year Mr. H. M. Knight has been added to the force of the division as a miscellaneous engraver, and Mr. W. H. Davis returned from his temporary employment in the office of the assistant in charge.

Messrs. J. Enthoffer, H. C. Evans, A. Sengteller, and A. M. Maedel have continued the engraving of the topography of the $\frac{1}{80000}$ scale coast series.

Messrs. John Knight, E. A. Maedel, and A. Petersen have continued as letter-engravers.

The miscellaneous engraving has been executed by Messrs. H. S. Barnard, J. C. Kondrup, R. F. Bartle, W. A. Thompson, H. M. Knight, J. G. Thompson, F. W. Benner, E. H. Sipe, and W. H. Davis.

Mr. E. Molkow has continued the pantographing of outlines.

The views have been engraved by Mr. G. McCoy.

The clerical duties of the division have been performed by Mr. George A. Morrison.

The electrotyping and photographing operations have been continued by Mr. George Mathiot, assisted by F. Ober. Thirty electrotype copper-plates, mostly of the largest class, having between 900 and 1,500 square inches surface, have been made during the year, part of which are altos, or relief-plates, from engraved plates; part bassos, or printing-plates.

The photographic reductions required for the use of the drawing and engraving divisions have been made as heretofore.

*Division of Charts and Instruments.*—The work in this division, which includes, besides the safe-keeping of archives, the map-printing, distribution of charts and reports, and the mechanician's and carpenter shops, has been directed during the year by Mr. J. T. Hoover.

The duty of registering and filing, for convenient reference, the original maps and charts of the survey, and the records of observations made in the field, and of keeping an account of the same, as they are used in the office, has been performed by Mr. A. Zumbrock.

During the year 391 original and 146 duplicate volumes of records of geodetical, hydrographical, and tidal observations have been received at the office; original topographical maps, 56; original hydrographical charts, 54; professional books and periodicals, 421 volumes. The copper-plate printing has been, as heretofore, acceptably done by Mr. T. V. Durham, who has turned out 8,352 impressions of charts, besides all the proofs required for office use.

Lithographic impressions were also procured to the number of 2,764 sheets.

The work of backing with muslin the sheets required by field and hydrographic parties, and the miscellaneous duties pertaining to the folding-room, were performed during the year by Mr. H. Nissen.

The map-room was in the care of Mr. Thomas McDonnell. An aggregate of 11,420 copies of charts have been issued within the year, and 16 copies of the Atlas of Harbors in Alaska, and 1,306 copies of Annual Reports of various years have been distributed.

The work in the instrument-shop was done, under the supervision of Mr. John Clark, by J. Foller, William Jacobi, Charles Wurdemann, and apprentice E. Eshleman.

The wood-work of instruments, their packing for transportation, the construction of cases for maps and copper-plates, and all work of carpentry required in the office, has been performed by Mr. A. Yeatman, assisted by Mr. F. E. Lackey.

Mr. V. E. King has continued in the performance of the duties of chief clerk of the office, having charge of the general correspondence and office accounts, assisted by Mr. Dallas B. Wainwright as writer. Mr. Clayton A. Hoover acted as writer in the hydrographic office.

In the office of the general disbursing agent of the Coast Survey, Samuel Hein, esq., the duties of principal accountant and book-keeper have been discharged with promptness and dispatch by Mr. R. L. Hawkins during the past as in many previous years, Mr. W. A. Herbert and Harry S. Hein acting as writers.

The ability with which the assistant in charge, J. E. Hilgard, esq., conducts the affairs of the office has relieved me from all anxiety in reference to that important division of the work. It is, too, a matter of just pride to mention here that his recognized knowledge and skill have been frequently invited and have been cheerfully enlisted in behalf of other departments of the public service, for deciding on practical questions of scientific import.

I would refer with pleasure to the new office quarters, in which, under an emergency constraining us to vacate the buildings heretofore occupied, the forethought and arrangements of the assistant in charge have secured accommodations long needed for the several branches of office-work, as well as for the Coast Survey archives and instruments.

With renewed satisfaction record is again made of the integrity and scrupulous care of the disbursing agent, Samuel Hein, esq., in regard to the accounts. By his conscientious adherence to regulations which limit the expenditure for outfit, and which in other respects apply to the prospective work, economy in the service has been steadily preserved.

I would recognize also, as heretofore, the clerical assistance rendered in the Superintendent's office by the skill of W. W. Cooper, esq., and his untiring fidelity in the discharge of adjunct duties under my personal direction.

Respectfully submitted.

BENJAMIN PEIRCE,
*Superintendent United States Coast Survey.*

Hon. GEORGE S. BOUTWELL,
*Secretary of the Treasury.*

# APPENDICES.

# APPENDIX No. 1.

*Distribution of surveying parties upon the Atlantic, Gulf, and Pacific Coasts of the United States, during the surveying seasons of 1869–'70.*

| Coast sections. | Parties. | Operations. | Persons conducting operations. | Localities of work. |
|---|---|---|---|---|
| SECTION I. | | | | |
| Atlantic Coast of Maine, New Hampshire, Massachusetts, and Rhode Island, including seaports, bays, and rivers. | No. 1 | Topography ...... | J. W. Donn, assistant; L. B. Wright, aid. | Topography of the shores of Moose-a-bec Reach, Me., and of the adjacent bay and islands, including Indian River and part of Chandler's Bay. (See also Section III.) |
| | 2 | Hydrography ..... | F. F. Nes, assistant; W. I. Vinal, aid; R. B. Palfrey, aid. | Hydrography of Moose-a-bec Reach and adjoining bays; and of the seaward approaches, extending to Crumple Island, including the development of numerous ledges. (See also Section IV.) |
| | 3 | Triangulation and measurement of heights. | G. A. Fairfield, assistant, W. B. Fairfield, aid. | Triangulation of Southwest Harbor, and of Somes' Sound, (Mount Desert Island, Me.,) and determination of the heights of stations in the vicinity. (See also Section IV.) |
| | 4 | Hydrography ..... | F. P. Webber, assistant; F. D. Granger, sub-assistant; Andrew Braid, aid. | Hydrography eastward of the Fox Island group, and of the southeastern and southern approaches to Isle au Haut Bay, Me., extending beyond Great Spoon Island and Seal Rock. (See also Section VIII.) |
| | 5 | Topography ...... | F. W. Dorr, assistant; H. M. De Wees, sub-assistant; Dion Bradbury, jr., aid. | Plane-table survey of the southeastern part of the Fox Island group, in Penobscot Bay, including the vicinity of Carver's Harbor, Me. (See also Sections II and IV.) |
| | 6 | Topography ...... | A. W. Longfellow, assistant; C. B. Fuller, aid. | Topography of the island group forming Gilkey's Harbor, in Penobscot Bay, near Camden, Me. |
| | 7 | Topography ...... | W. H. Dennis, assistant; G. W. Bissell, aid. | Detailed plane-table survey of Owl's Head Bay and Rockland Harbor, Me., including the adjacent islands between Clam Cove and Ash Point. (See also Section V.) |
| | 8 | Topography and hydrography. | C. H. Boyd, assistant; J. N. McClintock, aid; C. H. Van Orden, aid. | Survey of the banks of the Kennebec and soundings developing the channels of the river between Richmond and Gardiner, Me. Tides and currents observed. (See also Section VIII.) |
| | 9 | Topography ...... | Hull Adams, assistant; Eugene Ellicott, aid, (part of season;) O. H. Tittmann, aid, (part of season.) | Extension of the detailed survey of the coast of Maine, from Cape Porpoise northward to Old Orchard Beach, including the neighboring islands, and the mouth of Saco River. (See also Sections V and VI.) |
| | 10 | Reconnaissance... | G. W. Dean, assistant............ | Primary triangulation points in New England examined in reference to their connection with stations near Lake Champlain. (See also Section II.) |
| | 11 | Hydrography ..... | Horace Anderson, sub-assistant; F. W. King, aid. | In-shore soundings along the coast of New Hampshire and Massachusetts, from Portsmouth entrance southward to the mouth of Merrimac River. Additional soundings, completing the hydrography of Duxbury Harbor and Plymouth Harbor, Mass. (See also Section VI.) |
| | 12 | Longitude ........ | Professor Joseph Winlock ........ | Astronomical observations at Cambridge Observatory, and telegraphic exchanges to determine the longitude of Burlington, Vt. |
| | 13 | Topography ...... | H. L. Whiting, assistant; O. H. Tittmann, aid. | Topographical surveys, including tide-lands in the vicinity of Marshfield and Scituate, on the coast of Massachusetts. (See also Section V.) |

APPENDIX No. 1—Continued.

| Coast sections. | Parties. | Operations. | Persons conducting operations. | Localities of work. |
|---|---|---|---|---|
| SECTION I—Continued. | No. 14 | Astronomical and telegraphic observations. | G. W. Dean, assistant; Edward Goodfellow, assistant; F. Blake, jr., sub-assistant; J. Lawrence Wilde, aid. | Longitude determination by the exchange of time-signals through the French Atlantic cable between Duxbury, Mass., and Brest, on the coast of France. Connection of the station at Duxbury, with the primary triangulation and, by telegraphic observations, with Cambridge Observatory. (See also Sections II and III.) |
| | 15 | Physical hydrography. | Henry Mitchell, assistant; H. L. Marindin, sub-assistant; F. H. North, aid. | Physical researches at North River and at Green Harbor, Mass., relative to navigation as affected by dikes for reclaiming tide lands. (See also Sections II and X.) |
| | 16 | Triangulation | S. C. McCorkle, assistant | Determination of points for the survey of Saughkonnet River, R. I. (See also Sections II and VII.) |
| | 17 | Topography | A. M. Harrison, assistant; Charles Hosmer, assistant; C. T. Iardella, assistant; H. G. Ogden, sub-assistant; A. P. Barnard, aid. | Detailed topography of Newport Island and of the shores of Saughkonnet River, in continuation of the survey of the shores of Narragansett Bay, R. I. (See also Sections V and VII.) |
| | | Tidal observations. | J. G. Spaulding, H. Howland | Series of observations continued with self-registering tide-gauges at North Haven (Penobscot Bay) and at Charlestown Navy-yard. |
| SECTION II. Atlantic coast and seaports of Connecticut, New York, New Jersey, Pennsylvania, and Delaware, including bays, and rivers, and also Lake Champlain. | 1 | Reconnaissance | R. M. Bache, assistant | Examination of station points in the vicinity of New Haven Harbor. Tidal observations and determination of heights in and near New Haven. |
| | 2 | Reconnaissance | Richard D. Cutts, assistant; F. W. Perkins, sub-assistant; B. A. Colonna, aid. | Reconnaissance and selection of sites for bases, and for the course and extent of triangulation required in the survey of Lake Champlain, Vt. and N. Y. Measurement of preliminary base near Burlington, Vt. |
| | 3 | Astronomical observations. | A. T. Mosman, assistant; Edwin Smith, aid. | Latitude determined at a station in Burlington, Vt., and azimuth for the triangulation of the vicinity. |
| | 4 | Telegraphic operations. | G. W. Dean, assistant | Longitude of Burlington, Vt., determined by time signals exchanged with the Cambridge Observatory. (See also Section I.) |
| | 5 | Triangulation | J. A. Sullivan, assistant; B. A. Colonna, aid. | Triangulation over Lake Champlain from Burlington, Vt., and Colchester Point, westward to Ligonier Point and Ausable River. |
| | 6 | Triangulation | S. C. McCorkle, assistant; F. Stover, aid. | Triangulation from Plattsburgh, N. Y., eastward over Lake Champlain to South Hero Island, and southward to Ausable River. (See also Sections I and VII.) |
| | 7 | Topography | F. W. Dorr, assistant; Dion Bradbury, jr., aid. | Shore-line survey of the east side of Lake Champlain from Dunder Rock to Colchester Point, and of the western shore from Point Trembleau to Port Jackson. (See also Sections I and IV.) |
| | 8 | Topography | Charles Hosmer, assistant | Shore-line survey of Plattsburgh Harbor and of Lake Champlain, from Cumberland Head to Port Jackson, including also that of South Hero Island. (See also Sections I and V.) |
| | 9 | Hydrography | Charles Junken, assistant; Joseph Hergesheimer, aid. | Soundings in Lake Champlain, including Cumberland Bay and Plattsburgh Harbor, and extended southward to Valcour's Island. (See also Section V.) |
| | 10 | Topography and hydrography. | F. H. Gerdes, assistant; C. P. Dillaway, aid. | Survey of islands on west banks for quarantine in New York Bay. Verification of the positions of buoys and sea-marks in New York Bay, Raritan Bay, East River, Long Island Sound, and Fisher's Island Sound. Soundings on Diamond Reef, on the Oil Spot, and on Flynn's Knoll. |

APPENDIX No. 1—Continued.

| Coast sections. | Parties. | Operations. | Persons conducting operations. | Localities of work. |
|---|---|---|---|---|
| SECTION II—Continued. | No. 11 | Physical hydrography. | Henry Mitchell, assistant; H. L. Marindin, sub-assistant; F. H. North, aid. | Researches continued for developing the conditions dependent upon the tidal currents of East River and Long Island Sound. (See also Sections I and X.) |
| | 12 | Altitudes | Richard D. Cutts, assistant; F. H. Agnew, sub-assistant; Charles Ferguson, sub-assistant; Edwin Smith, C. L. Gardner, B. A. Colonna, and Charles Wurdemann, aids. | Barometrical observations and lines of level to determine heights above mean tide of the primary triangulation stations between Hudson River and Delaware Bay. |
| | 13 | Reconnaissance | W. S. Edwards, assistant, (part of season;) F. W. Perkins, sub-assistant, (part of season.) | Examination and selection of stations eastward of Mount Holly, N. J., for connecting Barnegat with the primary triangulation. (See also Sections IV and V.) |
| | 14 | Inspection | John Farley, assistant | Primary stations in New Jersey and Pennsylvania examined with reference to their security for future purposes. |
| | 15 | Topography | C. M. Bache, assistant; H. W. Bache, sub-assistant. | Plane-table survey extended on the coast of New Jersey, from Great Bay southward to Absecom and Atlantic City. (See also Section V.) |
| | | Tidal observations | R. T. Bassett | Series continued with the self-registering tide-gauge at Governor's Island, in New York Harbor. |
| SECTION III. Atlantic coast and bays of Maryland and Virginia, including sea-ports and rivers. | 1 | Astronomical observations and primary triangulation. | C. O. Boutelle, assistant; F. Blake, jr., sub-assistant; A. H. Scott, aid. | Peach Grove station, in Virginia, near the Potomac, and Maryland Heights, near Harper's Ferry, occupied for extending the primary triangulation south of Washington City. Determinations of latitude, azimuth, and the magnetic elements. (See also Section V.) |
| | 2 | Triangulation | R. E. Halter, assistant | Triangulation connecting the James River base line with stations on Chesapeake Bay, and extension of the river triangulation from the mouth upwards, to Jamestown, Va. |
| | 3 | Topography | J. W. Donn, assistant; L. B. Wright, aid; B. A. Colonna, aid. | Topography of the shores of the *Broad Water*, on the coast of Virginia, north of Cape Charles, between Machipongo Inlet and Magothy Bay. (See also Section I.) |
| | 4 | Topography and hydrography. | W. W. Harding, sub-assistant; A. F. Pearl, aid. | Hydrography of the Broad Water, on the sea-coast of Virginia. Shore-line survey and soundings in Maryland, including Chester River, Eastern Bay, Saint Michael's River, the Choptank, and other branches of Chesapeake Bay. |
| | | Magnetic observations. | Charles A. Schott, assistant | Magnetic declination, dip, and intensity observed at a station in Washington City. |
| | | Tidal observations | E. F. Krebs, W. J. Bodell | Series of tidal observations continued with a self-registering gauge, at Old Point Comfort, Va. |
| SECTION IV. Atlantic coast and sounds of North Carolina, including sea-ports and rivers. | 1 | Hydrography | Acting Master Robert Platt, U. S. N., assistant; Gershom Bradford, sub-assistant; J. B. Adamson, aid. | Hydrography of the coast of North Carolina, extended from abreast of Albemarle Sound southward to Cape Hatteras. (See also Section VI.) |
| | 2 | Triangulation and measurement of base. | G. A. Fairfield, assistant; F. W. Perkins, sub-assistant; W. B. Fairfield, aid. | Triangulation continued in Pamplico Sound, N. C., and extended up the Pamplico River as far as Washington, N. C. Measurement of base-line on the ocean beach, near Ocracoke Inlet. (See also Section I.) |

APPENDIX No. 1—*Continued.*

| Coast sections. | Parties. | Operations. | Persons conducting operations. | Localities of work. |
|---|---|---|---|---|
| SECTION IV—Continued. | No. 3 | Topography ...... | F. W. Dorr, assistant; H. M. De Wees, sub-assistant. | Plane-table survey of the shores of Pamplico River, N. C., and its branches, from the junction with Pungo River upwards to Lee's Creek. (See also Sections I and II.) |
| SECTION V. Atlantic coast and sea-water channels of South Carolina and Georgia, including sounds, harbors, and rivers. | 1 | Reconnaissance ... | W. S. Edwards, assistant......... | Examination of station-marks in the triangulation between Cape Roman and Charleston, S. C. (See also Section II.) |
| | 2 | Triangulation ..... | C. O. Boutelle, assistant.......... | Angular measurements at stations on the sea-islands of South Carolina, completing the primary triangulation between Charleston Harbor and the Savannah River. (See also Section III.) |
| | 3 | Topography ...... | Charles Hosmer, assistant........ | Plane-table survey, including parts of May River and Mackay's Creek, in the vicinity of Bluffton, S. C., and topography of the north side of the Savannah River, including part of Wright's River. (See also Sections I and II.) |
| | 4 | Hydrography ..... | F. F. Nes, assistant; C. P. Dillaway, aid; Joseph Hergesheimer, aid. | Soundings in the mouth of Pamplico River, Brant Island Shoal, and Long Bay sounded, and extension of the hydrography northward of the Pamplico entrance to Core Sound; hydrographic re-survey of the western entrance to Cape Fear River. (See also Section I.) |
| SECTION VI. Atlantic and Gulf coasts of the Florida Peninsula, including the reefs and keys, and the seaports and rivers. | 1 | Hydrography ..... | Horace Anderson, sub-assistant; R. B. Palfrey, aid. | Soundings north of Saint Augustine, Fla., developing the Tolomato and Guano Rivers; hydrography of Saint Augustine Harbor and bar, and of the Matanzas River southward to Matanzas Inlet. (See also Section I.) |
| | 2 | Topography ...... | J. G. Oltmanns, assistant; Eugene Ellicott, aid. | Plane-table survey, including the shore of the main-land, and the principal keys in Barnes' Sound and Chatham Bay, inside of the Florida Reef. (See also Section I.) |
| | 3 | Hydrography ..... | Acting Master Robert Platt, U. S. N., assistant; Gershom Bradford, sub-assistant; J. B. Adamson, aid. | Hydrography of the Florida Reef, extended in the vicinity of the Marquesas, including the "Quicksands," and Isaac and Rebecca Shoals; development of Marquesas Rock and of shoals on the Quicksand. (See also Section IV.) |
| | 4 | Topography ...... | C. M. Bache, assistant; Edwin Smith, aid; H. W. Bache, sub-assistant, (part of season.) | Details of topography completing the plane-table survey of Saint Andrew's Sound, Ga. (See also Section II.) |
| | 5 | Topography ...... | W. H. Dennis, assistant; O. H. Tittmann, aid. | Topography of Cumberland Island, Ga., and survey to the westward, including the banks of Cumberland River and its connecting waters with the adjacent marshes. (See also Section I.) |
| | 6 | Hydrography ..... | Charles Junken, assistant; W. I. Vinal, aid; G. W. Bissell, aid. | Soundings abreast of Cumberland Island, Ga., connecting the hydrography of Saint Andrew's Sound with that of Cumberland Sound, and development of the tide-water channels west of the island. (See also Sections I and II.) |
| SECTION VII. Gulf coast and sounds of Western Florida, including the ports and rivers. | 1 | Triangulation and topography. | S. C. McCorkle, assistant; C. T. Iardella, assistant. | Measurement of base-line on the beach of Saint Andrew's Bay, Fla., and triangulation and plane-table survey of the eastern and northern branches of the bay. (See also Sections I and II.) |
| SECTION VIII. Gulf coast and bays of Alabama, and the sounds of Mississippi and Louisiana to Vermilion Bay, including the ports and rivers. | 1 | Hydrography ..... | F. P. Webber, assistant; F. D. Granger, sub-assistant; Andrew Braid, aid. | Hydrography of Lake Borgne, west of Saint Joseph's Island, and of the eastern part of Lake Pontchartrain, including also the Rigolets and Lake Saint Catharine. (See also Section I.) |

APPENDIX No. 1—Continued.

| Coast sections. | Parties. | Operations. | Persons conducting operations. | Localities of work. |
|---|---|---|---|---|
| SECTION VIII—Continued. | No. 2 | Triangulation and topography. | C. H. Boyd, assistant; J. N. McClintock, aid. | Triangulation and plane-table survey of the shores of Isle au Breton Sound, La., completed; detailed survey of the banks of the Mississippi River continued upwards to Grand Prairie, above Fort Jackson. (See also Section I.) |
| SECTION X. | | | | |
| Pacific coast of California, including the bays, harbors, and rivers. | 1 | Triangulation and astronomical observations. | George Davidson, assistant: S. R. Throckmorton, jr., aid. | Santa Barbara, San Buenaventura, and West Beach stations occupied for the main triangulation of the Santa Barbara Channel. Longitude of Los Angeles, Cal., determined by the telegraphic method. Latitude and azimuth observed at Dominguez Hill in the Los Angeles Plains. Magnetic elements determined at that station and at Santa Barbara and San Buenaventura. (See also Section XI.) |
| | 2 | Topography and tertiary triangulation. | A. W. Chase, sub-assistant: M. Lipowitz, aid. | Topography and tertiary triangulation of the coast of California from Point Fermin to Point Vincente. |
| | 3 | Topography, triangulation, and hydrography. | W. E. Greenwell, assistant; Stehman Forney, aid. | Plane-table survey and tertiary triangulation of the coast of Santa Barbara Channel from Point Gorda to San Buenaventura, including a survey of the town. Topography of Santa Barbara and of the coast of California westward to the Goleta. Hydrography of the harbor of San Buenaventura. |
| | 4 | Hydrography ..... | Edward Cordell, assistant......... | Hydrographic development in the vicinity of Piedras Blancas, on the coast of California. |
| | 5 | Aids for navigation. | George Davidson, assistant; G. Farquhar, sub-assistant; S. R. Throckmorton, jr., aid. | Selection of sites and determination of the positions of buoys on Presidio Shoal in San Francisco entrance, and for the Boneta Channel. (See also Section XI.) |
| | 6 | Astronomical observations. | George Davidson, assistant: S. R. Throckmorton, aid. | Longitude of Point Arena determined by the telegraphic method. Latitude determined and the magnetic declination observed at the same station. Reconnaissance of the coast of California from Russian River to a station northward of Point Arena. (See also Section XI.) |
| | 7 | Topography and triangulation. | L. A. Sengteller, sub-assistant; H. Vincent, aid, (part of season;) Charles Schenk, aid, (part of season.) | Topography and tertiary triangulation of the vicinity of Point Arena, including Arena Cove, on the coast of California. |
| | 8 | Topography and triangulation. | Aug. F. Rodgers, assistant: E. F. Dickins, aid. | Plane-table survey and triangulation of the shores of Humboldt Bay, Cal.; and of the coast northward to Gihon's Bluff. Soundings in the bay, and at the mouth of Eel River. |
| | 9 | Hydrography ..... | George Farquhar, sub-assistant; F. Westdahl, aid. | Hydrography of Humboldt Bay, including the bar and the approaches. |
| | 10 | Topography and triangulation. | A. W. Chase, sub-assistant; M. Lipowitz, aid, (part of season;) M. Uhlig, aid, (part of season.) | Plane-table survey and triangulation from Crescent City northward, including Lake Earl and the coast of California and Oregon, with the adjacent rocks and reefs, to Chetko River. |
| | 11 | Physical hydrography. | Henry Mitchell, assistant; H. H. D. Peirce, aid; F. H. North, aid. | Special observations on the tidal currents of San Francisco Bay, in the vicinity of Yerba Buena Island. (See also Sections I and II.) |
| | | Tidal observations. | Major G. H. Mendell, U. S. Corps of Engineers; William Knapp, F P. Thompson. | Series of observations continued at San Diego and at Fort Point near San Francisco with self-registering tide-gauges. (See also Section XI.) |

## APPENDIX No. 1—Continued.

| Coast sections. | Parties. | Operations. | Persons conducting operations. | Localities of work. |
|---|---|---|---|---|
| SECTION XI. | | | | |
| Pacific coast of Oregon and of Washington Territory, including the interior bays, ports, and rivers. | No. 1 | Topography ...... | Cleveland Rockwell, assistant; G. H. Wilson, aid, (part of season.) | Plane-table survey of the north shore of Columbia River, Oregon, from Chinook Point to Three-Tree Point; and detailed topography of the south shore, and of the islands in the river, as far up as Cathlamet Head. |
| | 2 | Magnetic observations. | George Davidson, assistant; S. R. Throckmorton, jr., aid. | Magnetic declination determined at Astoria and at Portland. (See also Section X.) |
| | 3 | Triangulation, topography, and hydrography. | James S. Lawson, assistant; J. J. Gilbert, aid. | Triangulation from Port Discovery to New Dungeness; also at the south entrance of Rosario Strait; and from Puget Sound to Muck Prairie, Wash. Ter. Topography of the shore of the Strait of Fuca from Port Discovery to New Dungeness, including Washington Harbor; and from Point Wilson to Ross station; also of the vicinity of Admiralty Head; and of Smith's Island and Minor Island. Discovery and partial development of rocks in the south entrance Rosario Strait. |
| | | Tidal observations. | Major G. H. Mendell, U. S. Corps of Engineers; L. Wilson. | Observations continued with the self-registering tide-gauge at Astoria. (See also Section X.) |

# APPENDIX No. 2.

*Information furnished from the Coast Survey Office, by tracings from original, &c., in reply to special calls, during the year ending November 1, 1870.*

| Date. | | Names. | Information furnished. |
|---|---|---|---|
| 1869. | | | |
| December | 17 | Engineer Bureau | Hydrographic and topographical surveys of Lower Cedar Point and vicinity, Md. |
| | 17 | ........do | Topographical survey of Hawkins' Point, Patapsco River, Md. |
| 1870. | | | |
| January | 11 | John Wilson, esq | Hydrographic survey of the East River, from Pier No. 8 to Pier No. 45. |
| | 19 | I. E. Simpson, esq., New York | Compiled map of League Island, Delaware River. |
| | 27 | Engineer Bureau | Topographical survey of the Virginia side of the Potomac River, from Mount Vernon to Fort Lyon. |
| | 28 | Elisha Dyer, esq | Hydrographic survey part of Narragansett Bay, including Wickford Bay, Saughkonnet River, and the west side of the island of Rhode Island. |
| March | 2 | T. L. Patterson, esq | Topography adjacent to the northwest corner of the District of Columbia. |
| | 2 | Hon. T. W. Ferry, Mich | Shore-line measurements of the northern lakes. |
| | 2 | T. S. Sedgwick, chief engineer, western division Memphis, El Paso, and Pacific Railroad. | Triangulation data of San Diego Bay, Cal. |
| | 9 | Engineer Bureau | Topographical and hydrographic survey of Cape Cod and bay, from the Pamet River to North Branch. |
| | 9 | J. J. Lee, esq., Bucksport, Me | Shore-line survey of the Penobscot River, from Hampden to Bangor, Me. |
| | 14 | John Wilson, esq | Hydrographic survey of the Hudson River, vicinity of Twenty-third street, N. Y. |
| | 14 | Cape Cod Railroad Company | Topographical survey of Cape Cod, from Orleans to East Harbor. |
| | 17 | Trustees of the town of San Buenaventura, Cal | Topographical and hydrographic survey of San Buenaventura and approaches. |
| | 21 | Navy Department | Topographical and hydrographic survey of the Hudson River, from Sing Sing to Haverstraw. |
| | 21 | ........do | Topographical and hydrographic survey of the Hudson River, from Yonkers to Piermont. |
| April | 5 | W. H. Aspinwall, esq | Hydrographic and topographical map of Newport News Point, Va. |
| | 8 | Edward P. Clark, secretary Yale Navy | Hydrographic survey of the Thames River, from Winthrop's Point to Gales Ferry. |
| | 19 | Navy Department | Hydrographic survey of the Hudson River, from Verplanck's Point to Peekskill. |
| | 19 | W. H. Aspinwall, esq | Topographical and hydrographic survey of the York River, vicinity of Yorktown, Va. |
| May | 4 | Delaware River Bridge Company | Hydrographic survey of the Delaware River, adjacent to the city of Philadelphia. |
| | 7 | Howard Potter, esq | Topographical survey coast of New Jersey, from above Long Branch to Long Pond. |
| | 7 | ........do | Topographical survey coast of New Jersey, from above Long Branch to Poplar Creek from survey of 1839. |
| | 12 | W. Lee Apthorp, esq | Topographical survey of shores of Matanzas Inlet and vicinity, Fla. |
| | 16 | Boston Harbor Commissioners | Projections, with shore-line of Boston Bay and Harbor. |
| | 17 | Brevet Maj. Gen. J. G. Foster, Corps of Engineers | Hydrographic survey, head of Buzzard's Bay, Mass. |
| | 19 | H. M. Field, esq | Topography vicinity of Point Isabel, Tex. |
| | 19 | Light-house Board | Hydrographic survey, vicinity of Race Rock, Long Island Sound. |
| | 23 | ........do | Hydrographic survey of Fairfield Bar and Black Rock Harbor, Conn. |
| | 25 | Engineer Bureau | Hydrography of the Delaware River, off Hog Island, from the surveys of 1845 and 1862. |
| | 26 | Chesapeake and Ohio Railroad Company | Shore-line and hydrographic survey of the James River, from Mayo's Bridge to below Drury's Bluff, Va. |
| June | 1 | G. Lehlbach, chief engineer Port Royal railroad | Topographical survey of Port Royal Island, vicinity of Beaufort. |
| | 10 | Hon. W. A. Wheeler, Cal. (?) | Topographical survey of Yerba Buena Island, Cal., with vertical section of same. |
| | 10 | Hon. E. Degener, esq | Hydrographic survey of Corpus Christi Bay, including Corpus Christi and Aransas Pass, Tex. |
| | 17 | Hon. H. A. Reeves, N. Y | Coast-line measurements of Long Island and adjacent islands. |
| July | 11 | General Hartman Bache, Corps of Engineers | Topographical survey of the peninsula of Cape May, N. J. |

APPENDIX No. 2—Continued.

| Date. | | Names. | Information furnished. |
|---|---|---|---|
| 1870. | | | |
| July | 26 | Light-house Board | Hydrographic survey approaches to Greenport, Long Island. |
| August | 5 | Engineer's office, Fifth Light-house district | Hydrographic survey off Love Point, north end of Kent Island, Chesapeake Bay. |
| | 5 | Department of Docks, N. Y. | Hydrographic survey of the Hudson River, from Caven's Point to Guttenburg Ferry. |
| | 5 | ...do | Hydrographic survey of the East River, from Governor's Island to Ward's Island. |
| | 11 | Engineer Bureau | Topographical and hydrographic survey of Roanoke Sound, vicinity of Old Inlet. |
| | 13 | ...do | Hydrography and topography of Queenstown Harbor, Md. |
| | 13 | ...do | Hydrography and topography of Cambridge Harbor, Md. |
| | 15 | ...do | Hydrographic survey of Christiana Creek, from Wilmington to its mouth, Del. |
| | 17 | ...do | Hydrographic survey of the Delaware River, from Trenton to Newbold's Island. |
| | 18 | ...do | Topographical and hydrographic survey of Salem Creek, from town of Salem to the Delaware River. |
| | 25 | R. S. Chew, esq., State Department | Topography of Broad River, Whale Branch, and tributaries, and Pocotaligo and vicinity, S. C. |
| | 25 | Engineer Bureau | Shore-line and hydrographic survey coast of New Jersey, Shrewsbury River and Inlet, made in 1840. |
| | 25 | ...do | Shore-line coast of New Jersey, Shrewsbury River to Highlands of Navesink, from survey of 1864–'65. |
| | 25 | ...do | Map of South River, showing its junction with the Raritan River. |
| September | 3 | Colonel W. P. Craighill, Corps of Engineers | Hydrographic survey of the James River, from Mayo's Bridge to Drury Island, with table of borings. |
| | 5 | F. L. Olmstead, esq | Topographical survey of Staten Island, N. J. |
| | 7 | Lieutenant-Colonel J. D. Kurtz, Corps of Engineers | Hydrographic surveys of the mouth of Schuylkill River, made in 1843 and 1866. |
| | 7 | Colonel W. P. Craighill, Corps of Engineers | Hydrographic and topographical surveys of the Rappahannock River, from Fredericksburg to Hayfield. |
| | 24 | Colonel J. H. Simpson, Corps of Engineers | Hydrography off Benonis Point, Choptank River, Md. |
| | 30 | Captain C. W. Howell, Corps of Engineers | Hydrographic survey of Corpus Christi Pass, Tex. |
| | 30 | Major G. K. Warren, Corps of Engineers | Topographical survey of Block Island and adjacent hydrography. |
| | 30 | ...do ...do | Hydrographic and topographical survey of Pawcatuck River, Conn. |
| | 30 | ...do ...do | Hydrographic and topographical survey of Southport Harbor, Conn. |
| | 30 | ...do ...do | Hydrographic and topographical survey of Narragansett Pier to Boston Neck. |
| | 30 | ...do ...do | Hydrographic and topographical survey of Peconic River, Long Island, N. Y. |
| | 30 | ...do ...do | Hydrographic and topographical survey of Port Jefferson Harbor, Long Island, N. Y. |
| | 30 | ...do ...do | Hydrographic and topographical survey of Housatonic River, Conn. |
| October | 4 | Dr. E. W. Hilgard, State geologist of Mississippi | Topographical and hydrographic survey of the Southwest Pass, Mississippi Delta. |
| | 4 | Lieutenant-Colonel John Newton, Corps of Engineers | Topographical and hydrographic survey of the Narrows, N. Y. |
| | 4 | J. S. Shipman, esq | Topographical survey of the northwestern part of Long Island, including Astoria, Hunter's Point, and Newtown. |
| | 7 | Colonel W. P. Craighill, Corps of Engineers | Hydrographic survey of Harrison Bar, James River. |
| | 7 | ...do ...do | Hydrographic survey of Hog Island Bar, James River. |
| | 7 | ...do ...do | Hydrographic survey of the James River, from Drury Island to Rockdale Creek. |
| | 11 | Light-house Board | Hydrographic survey of Alligator Reef, Fla. |
| | 13 | Colonel W. P. Craighill, Corps of Engineers | Hydrographic survey of the James River, from Rockdale Creek to Curl's Neck. |
| | 20 | ...do ...do | Hydrographic survey of the James River, from Curl's Neck to City Point. |
| | 24 | Charles W. Baird, esq | Topographical survey of the northern shore of Long Island Sound, from Delancey Point to Calves Island, including the towns of Mamaroneck, Rye, and Port Chester. |
| | 24 | Engineer Bureau | Hydrographic and topographical survey, vicinity of Bull's Ferry, Hudson River. |

## APPENDIX No. 2—Continued.

| Date. | | Names. | Information furnished. |
|---|---|---|---|
| 1870. | | | |
| November | 4 | Prof. N. S. Shaler, State geologist of Massachusetts | Topographical map of the south side of Boston Harbor, from Neponset River to Weymouth Fore River. |
| | 12 | Henry J. Bigelow, esq | Topography head of Currituck Sound, North Carolina and Virginia. |
| | 28 | United States General Land-Office | Topographical surveys, in duplicates and triplicates, of the Florida Keys, from head of Key Biscayne Bay southward to Long Island, including the Keys of Barnes' Sound, and from Summerland Key to the Marquesas Keys, on township diagrams, scale $\frac{1}{31680}$. |
| | 29 | Hunter Davidson, in charge Maryland fisheries | Chesapeake Bay charts, scale $\frac{1}{80000}$, with buoys marked to date. |
| | 30 | Prof. N. S. Shaler, State geologist of Massachusetts | Topographical map, coast of Massachusetts, from town of Lynn to Salem. |
| December | 5 | E. T. D. Myers, superintendent R. F. and P. Railroad | Hydrography off Quantico and Chapowamsic Creeks, Potomac River. |
| | 10 | E. Fairfax Gray, engineer R., F. and P. Railroad | Do. Do. |
| | 19 | Colonel W. P. Craighill, Corps of Engineers | Hydrographic survey of parts of the Rappahannock River, Va., in the vicinity of Farleyvale, from Haugh Creek to Hop Yard Wharf, and on both sides of Mount Creek. |
| | 19 | Department of Docks, N. Y | Hydrographic survey of the Hudson River, from Weehawken to near New Baltimore, in six sheets. |

*Information furnished by Assistant George Davidson, from the office in San Francisco, during the year ending November* 1, 1870.

| | | | |
|---|---|---|---|
| 1869. | | | |
| June | 15 | George E. Gray, consulting engineer Central Pacific Railroad. | Charts of San Francisco; tracings from topography of San Francisco Peninsula. |
| October | — | Colonel R. S. Williamson, United States Army, light-house engineer. | Latitude and longitude of station at Pigeon Point. |
| November | 2 | General A. A. Humphreys, United States Army, Chief of Corps of Engineers. | Map of San Francisco Peninsula, embracing topography of one hundred square miles. |
| December | 6 | Colonel R. S. Williamson, United States Army, light-house engineer. | Chart of Santa Cruz Harbor and approaches. Latitude and longitude Santa Cruz light. |
| | 11 | Lieutenant Fechet, United States Army, Saint Paul's, Kadiak. | Charts of Alaska. |
| 1870. | | | |
| February | 4 | Major H. M. Robert, United States Army, major Corps of Engineers. | Three hundred charts of coast and harbors of California, Oregon, and Washington Territory. |
| | 12 | General B. S. Alexander, United States Army, senior officer Corps of Engineers, Pacific coast. | Tracing of sheets of Monterey Bay. |
| | | General B. S. Alexander, United States Army, Corps of Engineers. | Tracing of charts of Monterey Bay. |
| | | Admiral John R. Goldsborough, United States Navy, commandant Mare Island navy-yard. | Charts of the Pacific Coast. |
| 1869. | | | |
| December | 12 | Trustees of Santa Barbara | True meridian from station Santa Barbara, &c. |
| | 20 | Colonel R. S. Williamson, United States Army, light-house engineer. | Latitude, longitude, and elevation of Cape Mendocino Light. Latitude and longitude of Ediz Hook Light. |
| 1870. | | | |
| January | 8 | Hon. E. A. Rockwell, chairman committee on commerce and navigation, California legislature. | Charts of San Francisco Bay. |
| | 25 | Colonel R. S. Williamson, United States Army, light-house engineer. | Tracings of Yaquina Point and approaches and entrance to Yaquina River. |
| | 28 | General E. O. C. Ord, United States Army, commanding department of California. | Hydrography shores of Golden Gate. |
| February | 17 | Sherman Day, esq., United States surveyor-general, California. | Geographical position of Mount Diablo. |
| March | 9 | Master Samuel W. Very, United States Navy steamer Mohican. | Charts, western coast. |
| | 22 | General George P. Ihrie, United States Army | Charts, Pacific coast; harbors of Alaska; California and Alaska coast pilots. |
| April | 15 | Captain Watson Freeman, jr., United States quartermaster steamer Newbern. | Do. Do. |

APPENDIX No. 2—Continued.

| Date. | | Names. | Information furnished. |
|---|---|---|---|
| 1870. | | | |
| May | 19 | General E. O. C. Ord, United States Army, commanding department of California. | Charts of San Francisco Bay. |
| | 27 | Colonel R. S. Williamson, United States Army, light-house engineer. | Charts of entrance to Bay of San Francisco. |
| | 28 | Captain C. N. Scammon, revenue-cutter service, steamer Wayanda. | Coast and harbor charts of California, Oregon, Washington and Alaska. California and Alaska coast pilots. |
| | 30 | Major H. M. Robert, United States Army, Corps of Engineers. | Tracings of sheets of Alaska harbors. |
| June | 22 | Colonel Thomas S. Sedgwick, chief engineer, western division, Southern Pacific Railroad. | Datum plane low water, San Diego harbor. |
| | 26 | George H. Mumford, esq., president California State Tel. Co. | Chart, San Francisco Bay. |
| July | 10 | A. Provo Kliut, Naturalist, Academy of Natural Science, Netherlands. | Coast charts, California and Alaska coast pilots. |
| | 11 | Professor Walcott Gibbs | Charts Washington and Puget's Sound; coast charts and California coast pilot. |
| | 20 | Captain Lamy | Do. Do. |
| | 23 | General Canby, United States Army, commanding department of Columbia. | Chart Alaska; California and Alaska coast pilots. |
| | 23 | E. Davis Wheeler, esq | Tracing of islands in Suisun Bay. |
| | 24 | Colonel R. S. Williamson, United States Army, light-house engineer. | Height Cape Mendocino Light. |
| August | 5 | General R. O. Tyler, United States Army | Alaska coast pilot. |
| | 5 | General Tompkins, United States Army, Sitka, Alaska. | Do. |
| | 7 | Lieutenant George M. Wheeler, United States Army, San Francisco. | Do. |
| | 9 | General Schofield, United States Army, commanding department of California. | Do. |
| | 30 | Ed. P. Flint, esq., chief engineer, western division Northern Pacific Railroad. | Charts Washington and Puget Sounds. |
| October | 1 | Captain Frederick Bolles, steamer Oriflamme | Tracings Cape Orford and Crescent City Reefs; California coast pilot |
| | 1 | Captain Gregory, steamer Idaho | Do. Do. |
| | 9 | Captain Cox, Pacific Mail Steamship Company | Entrance chart and north sheet San Francisco Bay. |
| | 12 | General B. S. Alexander, United States Army, Corps of Engineers. | Charts Washington and Puget Sounds and Port Madison. |
| | 20 | Lieutenant George M. Wheeler, United States Army, commanding expedition to Colorado. | Field-transit, star list, 800 stars. |
| | 27 | Lieutenant C. B. Gill, United States Navy, sloop-of-war Cyane. | Charts and harbors of Alaska; California and Alaska coast pilots. |
| | 29 | General B. S. Alexander, United States Army, Corps of Engineers. | Chart of San Diego. |
| | 31 | Tide-land commissioners of California | Tracings of all the charts and maps of San Francisco Bay. |

# APPENDIX No. 3.

## DRAWING DIVISION.

*Charts completed or in progress during the year ending November 1, 1870.*

1. Hydrography. 2. Topography. 3. Drawing for photographic reduction. 4. Details on photographic outlines. 5. Verification. 6. Lettering.

| Title of charts. | Scale. | Draughtsmen. | Remarks. |
|---|---|---|---|
| Fox Island Thoroughfare, Me | 1-20, 000 | 1. A. Lindenkohl. 1. J. Sprandel. 1. L. Karcher | Prelim'ry; completed. |
| Coast chart No. 4, Naskeag Point to White Head light, including Penobscot Bay, Me. | 1-80, 000 | 3. F. Smith. 3. F. Fairfax. 3. L. Karcher. 4. H. Lindenkohl. | |
| Coast chart No. 5, White Head light to Seguin Island light, Me. | 1-80, 000 | 1. A. Lindenkohl. 3. L. Karcher. 4. H. Lindenkohl. | |
| Damariscotta and Medomak Rivers, Me | 1-40, 000 | 1. L. Karcher. 2. H. Lindenkohl. | |
| Casco Bay, Me | 1-40, 000 | 2. H. Lindenkohl | Additions; completed. |
| Coast chart No. 7, Seguin Island light to Cape Porpoise light, Me. | 1-80, 000 | 1. A. Lindenkohl | Additions; completed. |
| Boston Harbor, Mass | 1-40, 000 | 1. A. Lindenkohl | Additions; completed. |
| Coast chart No. 9, Boston Bay, Mass | 1-80, 000 | 1. A. Lindenkohl | Additions; completed. |
| Coast chart, No. 13, Narragansett Bay, R. I | 1-80, 000 | 3. F. Smith. 4. H. Lindenkohl. | |
| Wickford Harbor, R. I | 1-20, 000 | 1. F. Fairfax | Prelim'ry; completed. |
| Narragansett Bay, R. I., (upper sheet) | 1-40, 000 | 2. H. Lindenkohl. 2. F. Fairfax | Completed. |
| Atlantic coast No. I, Cape Sable to Sandy Hook | 1-1, 200, 000 | 1. A. Lindenkohl | Additions. |
| Atlantic coast, No. II, Nantucket to Cape Hatteras | 1-1, 200, 000 | 1. A. Lindenkohl | Additions. |
| Chesapeake and Delaware Bays | 1-400, 000 | 1. A. Lindenkohl. 2. A. Lindenkohl | Additions. |
| Coast chart No. 31, Entrance to Chesapeake Bay, including Hampton Roads. | 1-80, 000 | 1. A. and H. Lindenkohl. 2. A. and H. Lindenkohl. | Additions. |
| Coast chart No. 32, Chesapeake Bay, York River to Pocomoke Sound. | 1-80, 000 | 1. A. and H. Lindenkohl. 2. A. and H. Lindenkohl. | Additions. |
| Coast chart No. 33, Chesapeake Bay, Pocomoke Sound to Potomac River. | 1-80, 000 | 1. A. and H. Lindenkohl. 2. A. and H. Lindenkohl. | Additions. |
| Coast chart No. 34, Chesapeake Bay, Potomac River to Choptank River. | 1-80, 000 | 1. A. and H. Lindenkohl. 2. A. and H. Lindenkohl. | Additions. |
| Coast chart No. 35, Chesapeake Bay, Choptank River to Magothy River. | 1-80, 000 | 1. A. and H. Lindenkohl. 2. A. and H. Lindenkohl. | Additions. |
| Coast Chart No. 36, Chesapeake Bay, Magothy River to head of Bay. | 1-80, 000 | 1. A. and H. Lindenkohl. 2. A. and H. Lindenkohl. | Additions. |
| Patapsco River, Md | 1-60, 000 | 1. A. Lindenkohl | Additions. |
| Rappahannock River entrance, Va | 1-60, 000 | 2. H. Lindenkohl | Additions. |
| James River, from entrance to City Point, Va | 1-80, 000 | 1. A. Lindenkohl. 6. A. Lindenkohl | New edition; complet'd. |
| General coast chart No. V, Cape Henry to Cape Lookout, N. C. | 1-400, 000 | 1. A. and H. Lindenkohl. 2. A. and H. Lindenkohl. | Additions. |
| Wimble Shoals, N. C | 1-80, 000 | 1. A. Lindenkohl | New edition; complet'd. |
| Coast chart No. 54, Long Island to Hunting Island, including Charleston Harbor, S. C. | 1-80, 000 | 1. L. Karcher | Additions; completed. |
| General coast chart No. VII, Cape Roman to Saint Mary's River, Fla. | 1-400, 000 | 2. H. Lindenkohl | Additions. |
| Coast chart No. 55, Hunting Island to Ossabaw Sound, including Savannah River, Ga. | 1-80, 000 | 1. A. Lindenkohl. 1. L. Karcher | Completed. |
| Saint Catharine's Sound, Ga. | 1-40, 000 | 1. F. Fairfax. 2. F. Fairfax | Completed. |
| Coast chart No. 56, Savannah River to Doboy light, Ga | 1-80, 000 | 2. H. Lindenkohl. 4. H. Lindenkohl | |
| Doboy and Altamaha Sounds, Ga. | 1-40, 000 | 2. F. Fairfax | |
| Atlantic coast, No. VI, Mosquito inlet to Key West | 1-1, 200 000 | 1. A. Lindenkohl | Additions. |
| General coast chart No. X, Straits of Florida | 1-400, 000 | 1. A. Lindenkohl. 1. H. Lindenkohl. 2. H. Lindenkohl. | Additions. |
| Florida Reefs, (for United States Land-Office) | 1-31, 680 | 2. F. Smith | Completed. |
| Gulf of Mexico, Key West to Rio Grande, Texas | 1-1, 200, 000 | 1. A. Lindenkohl | Additions. |
| General coast chart No. XIII, Cape San Blas to Mississippi Delta, La. | 1-400, 000 | 2. H. Lindenkohl | Additions. |
| Coast chart No. 94, Mississippi Delta, La. | 1-80, 000 | 1. A. Lindenkohl. 2. H. Lindenkohl | |
| Coast chart No. 107, Matagorda Bay, Texas | 1-80, 000 | 1. H. Lindenkohl. 1. J. Sprandel. | |

APPENDIX No. 3—Continued.

| Title of charts. | Scale. | Draughtsmen. | Remarks. |
|---|---|---|---|
| Coast chart No. 109, Aramas and Copano Bays, Texas | 1-80, 000 | 1. H. Lindenkohl. 2. H. Lindenkohl | |
| Coast chart No. 110, Corpus Christi Pass and Bay, Texas. | 1-80, 000 | 1. H. Lindenkohl. 2. H. Lindenkohl | |
| Pacific coast, (middle sheet,) San Francisco to Umpquah River, Oregon. | 1-1, 200, 000 | 1, 2. A. Lindenkohl and H. Lindenkohl | Additions; engraving the same. |
| Pacific coast, Point Pinos to Bodega Sound, Cal | 1-200, 000 | 2. F. Fairfax | Additions. |
| Saint George's Reef and Crescent City, Cal | 1-40, 000 | 1, 2. H. Lindenkohl | |
| Cape Orford and reef, Oregon | 1-40, 000 | 1, 2. H. Lindenkohl | |
| Yaquina Bay, Oregon | 1-20, 000 | 2. F. Fairfax | Completed. |
| Columbia River Entrance | 1-40, 000 | 1. A. Lindenkohl. 1. H. Lindenkohl. 2. H. Lindenkohl. | |
| Pacific coast, (northern sheet,) Umpquah River to N. W. Boundary. | 1-1, 200, 000 | 1, 2. A. Lindenkohl and H. Lindenkohl | Additions; engraving the same. |
| Northwest coast, No. 1, Cape Flattery to Dixon Entrance. | 1-1, 200, 000 | 1. A. Lindenkohl. 2. A. and H. Lindenkohl | |
| Alaska Harbors | | 1, 2. H. Lindenkohl, for photo-lithographing | Completed. |
| Northwest coast No. II, Dixon Entrance to Cape Saint Elias. | 1-1, 200, 000 | 1, 2. A. Lindenkohl | |
| Alaska and adjoining territory | | A. and H. Lindenkohl, compiling | New edition; compl't'd. |
| Northwest coast, No. III, Icy Bay to Seven Islands | 1-1, 200, 000 | 1. A. Lindenkohl | |
| Formosa Island, (for photo-lithographing) | | H. Lindenkohl | Completed. |
| Amoy Tea District, (for photo-lithographing) | | L. Karcher | Completed. |

# APPENDIX No. 4.

## ENGRAVING DIVISION.

*Plates completed, continued, or commenced during the year ending November 1, 1870.*

1. Outlines. 2. Topography. 3. Sanding. 4. Lettering.

| Title of plates. | Scale. | Engravers. |
|---|---|---|
| COMPLETED. | | |
| Northwest coast of America, No. 1, (prelim. ed.) | 1-1,200,000 | 4. J. G. Thompson. |
| Puget Sound | 1-200,000 | 3. H. S. Barnard. 4. A. Petersen and J. G. Thompson. |
| Coast chart No. 27 | 1-80,000 | 4. J. G. Thompson. |
| Winter harbor | 1-20,000 | 3. F. W. Benner. 4. J. G. Thompson. |
| Greenwich Bay | 1-20,000 | 3. W. A. Thompson. 4. J. G. Thompson. |
| New York entrance | 1-40,000 | 2. A. Sengteller. 3. W. A. Thompson. 4. E. A. Maedel. |
| James River mouth to City Point | 1-80,000 | 1. E. H. Sipe. 3. W. A. Thompson. 4. J. G. Thompson and E. H. Sipe. |
| Potomac River No. 1 | 1-60,000 | 2. A. M. Maedel. 3. H. S. Barnard. 4. E. A. Maedel and J. G. Thompson. |
| Port of New Berne | 1-40,000 | 2. R. F. Bartle. 4. J. G. Thompson. |
| Wimble Shoals | 1-80,000 | 1, 3, and 4. E. H. Sipe. |
| Saint Helena Sound | 1-40,000 | 4. J. G. Thompson. |
| Port Madison | 1-20,000 | 2. W. A. Thompson. 3. F. W. Benner. 4. J. G. Thompson. |
| Plate of rules for lettering | ............ | 4. J. Knight. |
| CONTINUED. | | |
| General coast chart No. II, Cape Ann to Gay Head | 400,000 | 2. A. M. Maedel. |
| General coast chart No. V, Cape Henry to Cape Lookout | 400,000 | 2. A. M. Maedel. 3. H. S. Barnard. 4. E. A. Maedel. |
| General coast chart No. VII, Cape Roman to Saint Mary's River. | 400,000 | 1 and 2. A. M. Maedel. |
| General coast chart No. X, Straits of Florida | 400,000 | 4. A. Petersen and J. G. Thompson. |
| General coast chart No. XIII, Cape San Blas to Mississippi Delta. | 400,000 | 2. A. M. Maedel. 4. J. Knight. |
| Coast chart No. 4, Penobscot Bay | 1-80,000 | 1 and 2. J. Enthoffer. 4. E. A. Maedel. |
| Coast chart No. 5, Whitehead light to Seguin light | 80,000 | 1 and 2. J. Enthoffer. 4. E. A. Maedel and J. Knight. |
| Coast chart No. 8, Well's Beach to Cape Ann | 80,000 | 4. E. A. Maedel. |
| Coast chart No. 9, Boston Bay | 80,000 | 3. H. S. Barnard. 4. J. Knight. |
| Coast chart No. 28, Isle of Wight to Chincoteague | 80,000 | 3. F. W. Benner. 4. J. Knight. |
| Coast chart No. 31, entrance Chesapeake Bay | 80,000 | 1 and 2. A. Sengteller. 3. W. A. Thompson. 4. J. Knight. |
| Coast chart No. 32, Chesapeake Bay No. 2 | 80,000 | 1 and 2. A. Sengteller and H. C. Evans. 3. H. S. Barnard. 4. J. Knight. |
| Coast chart No. 33, Chesapeake Bay No. 3 | 80,000 | 1 and 2. A. Sengteller. 3. W. A. Thompson. 4. J. Knight. |
| Coast chart No. 55, Hunting Island to Ossabaw | 80,000 | 4. E. A. Maedel. |
| Coast chart No. 56, Savannah to Doboy light | 80,000 | 1 and 2. A. Sengteller. 4. J. Knight. |
| Coast chart No. 75, Charlotte Harbor | 80,000 | 2. J. C. Kondrup. |
| Coast chart No. 94, Mississippi River entrance | 80,000 | 4. E. A. Maedel. |
| Coast chart No. 105, Galveston Bay to Oyster Bay | 80,000 | 2. J. C. Kondrup and W. A. Thompson. 3. F. W. Benner. 4. A. Petersen. |
| Coast chart No. 107, Matagorda Bay | 80,000 | 3. F. W. Benner. 4. E. A. Maedel. |
| Damariscotta and Medomak Rivers | 1-40,000 | 1. R. F. Bartle and E. Molkow. 4. A. Petersen. |
| Casco Bay | 1-40,000 | 1. E. Molkow and W. A. Thompson. 3. H. S. Barnard and W. A. Thompson. 4. A. Petersen. |
| Boston Harbor | 1-40,000 | 2. J. Enthoffer. 3. H. S. Barnard. 4. E. A. Maedel and A. Petersen. |
| Narragansett Bay, (upper) | 1-40,000 | 1. R. F. Bartle. 2. H. C. Evans. 4. A. Petersen and E. A. Maedel. |
| New York Bay and Harbor, (upper) | 1-40,000 | 1. R. F. Bartle. 2. H. C. Evans and R. F. Bartle. 4. E. A. Maedel. |
| New York Bay and Harbor, (lower) | 1, 40,000 | 2. R. F. Bartle. |
| Potomac River No. 2 | 1-60,000 | 1 and 2. A. M. Maedel. 3. H. S. Barnard. 4. A. Petersen. |
| Saint Catharine's Sound | 1-40,000 | 1 and 2. W. A. Thompson. 3. F. W. Benner. 4. E. H. Sipe. |
| San Francisco Peninsula | 1-40,000 | 1. E. Molkow and J. C. Kondrup. |
| COMMENCED. | | |
| Northwest coast of America No. 2 | 1-1,200,000 | 1. R. F. Bartle. 4. F. Courtenay. |
| Northwest coast of America No. 3 | 1-1,200,000 | 1. R. F. Bartle. 4. F. Courtenay. |
| Fox Islands Thoroughfare | 1-20,000 | 1. J. G. Thompson. 3. H. M. Knight. 4. J. G. Thompson. |
| Wickford Harbor | 1-20,000 | 1. W. A. Thompson. 3. F. W. Benner. 4. E. H. Sipe and J. G. Thompson. |
| Local deflection of zenith near Washington, D. C | 1-400,000 | 1. W. A. Thompson. 2. H. S. Barnard. 4. E. A. Maedel. |
| Patapsco River, (new edition) | 1-60,000 | 3. F. W. Benner. 4. A. Petersen and J. G. Thompson. |
| Yaquina River entrance | 1-20,000 | 1. W. A. Thompson. 3. H. M. Knight. 4. J. G. Thompson. |
| Columbia River No. 1 | 1-40,000 | 1. R. F. Bartle. 3. F. W. Benner. 4. J. G. Thompson and E. H. Sipe. |

# APPENDIX No. 5.

## A TABULAR STATEMENT OF RESULTS COMPUTED FOR TIDE-TABLES FOR CHARTS OF THE WESTERN COAST OF THE UNITED STATES. BY R. S. AVERY.

The results given in the following tables were obtained by the process fully described in the Coast Survey report for 1868, pp. 103–108, and there exemplified by application to the tides observed at Sitka.

The following general statement applies to all places named in the tables.

The two tides of the same day are generally unequal in proportion to the moon's declination. The time and height can be obtained approximately from the following tables.

The interval is to be added to the time of the moon's meridian passage to give the time of high or low water. The time of the moon's upper meridian passage is given in the almanac, and the time of its lower meridian passage is the middle between two successive upper passages.

The heights are given in feet and tenths, and show the rise above the level of the average of the lowest low water; to which level the soundings on the charts are given.

*Spring-tides.*—At the full and change of the moon the high waters will be $a$ feet higher than the above, and the low waters $b$ feet lower.

*Neap-tides.*—At the moon's first and last quarters the high waters will be $c$ feet lower, and the low waters will not fall as low by $d$ feet.

The values of $a$, $b$, $c$, $d$, for each place will be given in the last column of the following tables:

| Place. | Moon's declination. | Moon's upper meridian passage. | | | | Moon's lower meridian passage. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | High water. | | Low water. | | High water. | | Low water. | | |
| | | Interval. | Height. | Interval. | Height. | Interval. | Height. | Interval. | Height. | |
| | | h. m. | Feet. | h. m. | Feet. | h. m. | Feet. | h. m. | Feet. | Feet. |
| Cape San Lucas | Greatest N | 8 04 | 4.3 | 15 37 | − 0.3 | 9 41 | 2.6 | 14 23 | 1.7 | a=+0.7<br>b=−0.8 |
| | Zero | 8 28 | 3.7 | 14 37 | 0.5 | 8 28 | 3.7 | 14 37 | 0.5 | c=−0.6 |
| | Greatest S | 9 41 | 2.6 | 14 23 | 1.7 | 8 04 | 4.3 | 15 37 | − 0.3 | d=+0.8 |
| San Diego | Greatest N | 8 53 | 5.6 | 16 16 | − 0.3 | 10 23 | 3.7 | 14 58 | 2.1 | a=+0.7<br>b=−0.7 |
| | Zero | 9 28 | 4.9 | 15 40 | 0.7 | 9 28 | 4.9 | 15 40 | 0.7 | c=−0.7 |
| | Greatest S | 10 23 | 3.7 | 14 58 | 2.1 | 8 53 | 5.6 | 16 16 | − 0.3 | d=+0.7 |
| San Pedro | Greatest N | 9 02 | 6.0 | 16 53 | − 0.7 | 11 02 | 3.7 | 15 20 | 2.5 | a=+0.5<br>b=−0.6 |
| | Zero | 9 16 | 4.6 | 15 27 | 1.1 | 9 16 | 4.6 | 15 27 | 1.1 | c=−0.5 |
| | Greatest S | 11 02 | 3.7 | 15 20 | 2.5 | 9 02 | 6.0 | 16 53 | − 0.7 | d=+0.6 |
| Cuyler's Harbor, (Island San Miguel.) | Greatest N | 7 39 | 5.6 | 15 52 | − 0.6 | 10 21 | 3.4 | 13 52 | 3.0 | a=+0.2<br>b=−0.4 |
| | Zero | 9 47 | 5.2 | 16 01 | 0.8 | 9 47 | 5.2 | 16 01 | 0.8 | c=−0.2 |
| | Greatest S | 10 21 | 3.4 | 13 52 | 3.0 | 7 39 | 5.6 | 15 52 | − 0.6 | d=+0.4 |
| Point Sal | Greatest N | 9 54 | 4.9 | 17 15 | − 0.0 | 11 13 | 3.4 | 16 16 | 2.2 | a=+0.6<br>b=−0.5 |
| | Zero | 9 30 | 4.7 | 15 50 | 0.4 | 9 30 | 4.7 | 15 50 | 0.4 | c=−0.6 |
| | Greatest S | 11 13 | 3.4 | 16 16 | 2.2 | 9 54 | 4.9 | 17 15 | − 0.0 | d=+0.5 |
| San Luis Obispo | Greatest N | 9 41 | 5.8 | 17 22 | − 0.8 | 11 59 | 3.8 | 16 20 | 2.6 | a=+0.6<br>b=−0.6 |
| | Zero | 9 26 | 4.8 | 15 28 | 0.9 | 9 26 | 4.8 | 15 28 | 0.9 | c=−0.6 |
| | Greatest S | 11 59 | 3.8 | 16 20 | 2.6 | 9 41 | 5.8 | 17 22 | − 0.8 | d=+0.6 |
| San Francisco, (North Beach) | Greatest N | 10 58 | 5.8 | 18 23 | − 0.7 | 13 32 | 4.3 | 17 31 | 3.2 | a=+0.4<br>b=−0.3 |
| | Zero | 12 02 | 4.8 | 17 55 | 1.1 | 12 02 | 4.8 | 17 55 | 1.1 | c=−0.4 |
| | Greatest S | 13 32 | 4.3 | 17 31 | 3.2 | 10 58 | 5.8 | 18 23 | − 0.7 | d=+0.3 |
| San Francisco, (Rincon Point) | Greatest N | 11 23 | 6.1 | 18 40 | − 0.8 | 13 29 | 4.5 | 17 54 | 2.9 | a=+0.6<br>b=−0.4 |
| | Zero | 11 26 | 4.9 | 17 20 | 1.0 | 11 26 | 4.9 | 17 20 | 1.0 | c=−0.6 |
| | Greatest S | 13 29 | 4.5 | 17 54 | 2.9 | 11 23 | 6.1 | 18 40 | − 0.8 | d=+0.4 |

*A tabular statement of results computed for tide-tables for charts of the western coast of the United States*—Continued.

| Place. | Moon's declination. | Moon's upper meridian passage. | | | | Moon's lower meridian passage. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | High water. | | Low water. | | High water. | | Low water. | | |
| | | Interval. | Height. | Interval. | Height. | Interval. | Height. | Interval. | Height. | |
| | | *h. m.* | *Feet.* | *h. m.* | *Feet.* | *h. m.* | *Feet.* | *h. m.* | *Feet.* | *Feet.* |
| Fort Point | Greatest N | 10 54 | 5.5 | 17 50 | — 0.5 | 12 50 | 4.1 | 17 09 | 2.6 | *a*=+0.3 |
| | Zero | 11 44 | 4.7 | 17 25 | 0.8 | 11 44 | 4.7 | 17 25 | 0.8 | *b*=—0.4 |
| | Greatest S | 12 50 | 4.1 | 17 09 | 2.6 | 10 54 | 5.5 | 17 50 | — 0.5 | *c*=—0.3 |
| | | | | | | | | | | *d*=+0.4 |
| Monterey | Greatest N | 8 46 | 5.8 | 16 47 | — 0.4 | 11 37 | 3.8 | 15 07 | 3.2 | *a*=+0.3 |
| | Zero | 10 38 | 4.6 | 16 51 | 1.0 | 10 38 | 4.6 | 16 51 | 1.0 | *b*=—0.4 |
| | Greatest S | 11 37 | 3.8 | 15 07 | 3.2 | 8 46 | 5.8 | 16 47 | — 0.4 | *c*=—0.3 |
| | | | | | | | | | | *d*=+0.4 |
| Santa Cruz | Greatest N | 10 12 | 6.7 | 16 22 | — 0.8 | 11 09 | 3.9 | 15 15 | 2.4 | *a*=+0.6 |
| | Zero | 10 20 | 5.2 | 15 53 | 1.2 | 10 20 | 5.2 | 15 53 | 1.2 | *b*=—0.4 |
| | Greatest S | 11 09 | 3.9 | 15 15 | 2.4 | 10 12 | 6.7 | 16 22 | — 0.8 | *c*=—0.6 |
| | | | | | | | | | | *d*=+0.4 |
| South Farallon | Greatest N | 9 48 | 6.0 | 17 38 | — 0.6 | 12 05 | 4.2 | 16 18 | 3.4 | *a*=+0.4 |
| | Zero | 10 26 | 4.9 | 16 44 | 1.2 | 10 26 | 4.9 | 16 44 | 1.2 | *b*=—0.4 |
| | Greatest S | 12 05 | 4.2 | 16 18 | 3.4 | 9 48 | 6.0 | 17 38 | — 0.6 | *c*=—0.4 |
| | | | | | | | | | | *d*=+0.4 |
| Mare Island | Greatest N | 12 35 | 7.3 | 20 22 | — 0.7 | 15 06 | 5.7 | 19 30 | 3.8 | *a*=+0.3 |
| | Zero | 13 32 | 6.3 | 19 43 | 1.3 | 13 32 | 6.3 | 19 43 | 1.3 | *b*=—0.2 |
| | Greatest S | 15 06 | 5.7 | 19 30 | 3.8 | 12 35 | 7.3 | 20 22 | — 0.7 | *c*=—0.3 |
| | | | | | | | | | | *d*=+0.2 |
| Benicia | Greatest N | 13 03 | 6.4 | 20 51 | — 0.4 | 15 56 | 5.2 | 20 05 | 3.6 | *a*=+0.3 |
| | Zero | 13 55 | 5.8 | 19 56 | 0.9 | 13 55 | 5.8 | 19 56 | 0.9 | *b*=—0.4 |
| | Greatest S | 15 56 | 5.2 | 20 05 | 3.6 | 13 03 | 6.4 | 20 51 | — 0.4 | *c*=—0.3 |
| | | | | | | | | | | *d*=+0.4 |
| Army Point, (Suisun Bay) | Greatest N | 12 57 | 7.0 | 20 15 | — 0.6 | 14 50 | 5.8 | 19 32 | 2.9 | *a*=+0.3 |
| | Zero | 14 11 | 5.8 | 20 14 | 1.3 | 14 11 | 5.8 | 20 14 | 1.3 | *b*=—0.1 |
| | Greatest S | 14 50 | 5.8 | 19 32 | 2.9 | 12 57 | 7.0 | 20 15 | — 0.6 | *c*=—0.3 |
| | | | | | | | | | | *d*=+0.1 |
| Collinsville, (Suisun Bay) | Greatest N | 13 40 | 5.0 | 21 47 | — 0.1 | 15 50 | 4.6 | 21 10 | 2.2 | *a*=+0.2 |
| | Zero | 15 18 | 5.2 | 22 11 | 0.3 | 15 18 | 5.2 | 22 11 | 0.3 | *b*=—0.4 |
| | Greatest S | 15 40 | 4.6 | 21 10 | 2.2 | 13 40 | 5.0 | 21 47 | — 0.1 | *c*=—0.2 |
| | | | | | | | | | | *d*=+0.4 |
| Peralta | Greatest N | 10 42 | 6.2 | 18 11 | — 0.5 | 12 38 | 4.8 | 17 33 | 3.3 | *a*=+0.5 |
| | Zero | 12 13 | 5.9 | 18 09 | 0.4 | 12 13 | 5.9 | 18 09 | 0.4 | *b*=—0.5 |
| | Greatest S | 12 38 | 4.8 | 17 33 | 3.3 | 10 42 | 6.2 | 18 11 | — 0.5 | *c*=—0.5 |
| | | | | | | | | | | *d*=+0.5 |
| Ravenswood | Greatest N | 11 19 | 7.9 | 18 39 | — 0.2 | 13 23 | 6.8 | 18 19 | 4.1 | *a*=+0.6 |
| | Zero | 12 55 | 8.1 | 19 10 | 0.8 | 12 55 | 8.1 | 19 10 | 0.8 | *b*=—0.6 |
| | Greatest S | 13 23 | 6.8 | 18 19 | 4.1 | 11 19 | 7.9 | 18 39 | — 0.2 | *c*=—0.6 |
| | | | | | | | | | | *d*=+0.6 |
| Bodega | Greatest N | 10 06 | 6.5 | 18 25 | — 0.5 | 12 38 | 4.1 | 16 46 | 3.1 | *a*=+0.6 |
| | Zero | 10 49 | 4.6 | 17 03 | 1.2 | 10 49 | 4.6 | 17 03 | 1.2 | *b*=—0.2 |
| | Greatest S | 12 38 | 4.1 | 16 46 | 3.1 | 10 06 | 6.5 | 18 25 | — 0.5 | *c*=—0.6 |
| | | | | | | | | | | *d*=+0.2 |
| Astoria | Greatest N | 12 04 | 8.1 | 19 39 | — 0.4 | 13 16 | 6.5 | 18 38 | 2.5 | *a*=+0.8 |
| | Zero | 12 05 | 7.5 | 19 14 | 0.8 | 12 05 | 7.5 | 19 14 | 0.8 | *b*=—0.5 |
| | Greatest S | 13 16 | 6.5 | 18 38 | 2.5 | 12 04 | 8.1 | 19 39 | — 0.4 | *c*=—0.8 |
| | | | | | | | | | | *d*=+0.5 |
| Humboldt Bay | Greatest N | 11 20 | 6.1 | 19 02 | — 0.5 | 13 26 | 4.2 | 17 39 | 3.0 | *a*=+0.5 |
| | Zero | 11 36 | 5.6 | 17 47 | 0.7 | 11 36 | 5.6 | 17 47 | 0.7 | *b*=—0.4 |
| | Greatest S | 13 26 | 4.2 | 17 39 | 3.0 | 11 20 | 6.1 | 19 02 | — 0.5 | *c*=—0.5 |
| | | | | | | | | | | *d*=+0.4 |
| Port Orford | Greatest N | 10 55 | 6.9 | 18 28 | — 0.3 | 12 58 | 5.0 | 17 21 | 3.6 | *a*=+0.3 |
| | Zero | 11 07 | 6.6 | 17 18 | 0.8 | 11 07 | 6.6 | 17 18 | 0.8 | *b*=—0.3 |
| | Greatest S | 12 58 | 5.0 | 17 21 | 3.6 | 10 55 | 6.9 | 18 28 | — 0.3 | *c*=—0.3 |
| | | | | | | | | | | *d*=+0.3 |

*A tabular statement of results computed for tide-tables for charts of the western coast of the United States*—Continued.

| Place. | Moon's declination. | Moon's upper meridian passage. High water. Interval. | Moon's upper meridian passage. High water. Height. | Moon's upper meridian passage. Low water. Interval. | Moon's upper meridian passage. Low water. Height. | Moon's lower meridian passage. High water. Interval. | Moon's lower meridian passage. High water. Height. | Moon's lower meridian passage. Low water. Interval. | Moon's lower meridian passage. Low water. Height. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | *h. m.* | *Feet.* | *h. m.* | *Feet.* | *h. m.* | *Feet.* | *h. m.* | *Feet.* | *Feet.* |
| **Koos Bay** | Greatest N | 12 26 | 5.6 | 20 08 | − 0.0 | 13 43 | 4.1 | 18 48 | 2.0 | a=+0.4, b=−0.5, c=−0.4, d=+0.6 |
| | Zero | 13 17 | 5.3 | 19 53 | 0.4 | 13 17 | 5.3 | 19 53 | 0.4 | |
| | Greatest S | 13 43 | 4.1 | 18 48 | 2.0 | 12 26 | 5.6 | 20 08 | − 0.0 | |
| **Yaquina Bay, (Newport)** | Greatest N | 11 17 | 7.7 | 18 09 | − 0.4 | 12 25 | 6.1 | 17 51 | 3.0 | a=+1.0, b=−0.6, c=−1.0, d=+0.6 |
| | Zero | 11 59 | 7.8 | 18 09 | 0.8 | 11 59 | 7.8 | 18 09 | 0.8 | |
| | Greatest S | 12 25 | 6.1 | 17 51 | 3.0 | 11 17 | 7.7 | 18 09 | − 0.4 | |
| **Oysterville, (Yaquina River)** | Greatest N | 11 08 | 7.6 | 18 38 | − 0.6 | 12 35 | 6.5 | 18 12 | 3.0 | a=+0.9, b=−0.9, c=−0.9, d=+0.9 |
| | Zero | 12 49 | 7.6 | 19 07 | 0.8 | 12 49 | 7.6 | 19 07 | 0.8 | |
| | Greatest S | 12 35 | 6.5 | 18 12 | 3.0 | 11 08 | 7.6 | 18 38 | − 0.6 | |
| **Tillamook Bay** | Greatest N | 11 13 | 7.3 | 18 45 | − 0.6 | 12 44 | 6.2 | 17 58 | 2.0 | a=+0.5, b=−0.7, c=−0.5, d=+0.7 |
| | Zero | 12 30 | 7.0 | 18 40 | 0.3 | 12 30 | 7.0 | 18 40 | 0.3 | |
| | Greatest S | 12 44 | 6.2 | 17 58 | 2.0 | 11 13 | 7.3 | 18 45 | − 0.6 | |
| **Fort Stevens, (Columbia River)** | Greatest N | 12 10 | 8.0 | 19 24 | − 0.4 | 13 30 | 6.2 | 18 30 | 2.6 | a=+0.8, b=−0.4, c=−0.8, d=+0.4 |
| | Zero | 12 00 | 7.6 | 18 18 | 0.6 | 12 00 | 7.6 | 18 18 | 0.6 | |
| | Greatest S | 13 30 | 6.2 | 18 30 | 2.6 | 12 10 | 8.0 | 19 24 | − 0.4 | |
| **Skipennon Creek, (Columbia River)** | Greatest N | 11 55 | 9.0 | 19 28 | − 0.9 | 12 58 | 7.5 | 18 19 | 2.7 | a=+0.4, b=−0.7, c=−0.4, d=+0.7 |
| | Zero | 12 35 | 7.3 | 18 59 | 1.6 | 12 35 | 7.3 | 18 59 | 1.6 | |
| | Greatest S | 12 58 | 7.5 | 18 19 | 2.7 | 11 55 | 9.0 | 19 28 | − 0.9 | |
| **Tongue Point, (Columbia River)** | Greatest N | 11 54 | 7.4 | 19 32 | − 0.1 | 13 01 | 6.4 | 18 34 | 2.6 | a=+0.8, b=−0.7, c=−0.8, d=+0.7 |
| | Zero | 13 25 | 7.5 | 20 11 | 0.5 | 13 25 | 7.5 | 20 11 | 0.5 | |
| | Greatest S | 13 01 | 6.4 | 18 34 | 2.6 | 11 54 | 7.4 | 19 32 | − 0.1 | |
| **Marsh Island Creek, (Columbia R.)** | Greatest N | 12 52 | 6.7 | 21 11 | − 0.5 | 14 01 | 5.3 | 19 53 | 1.6 | a=+0.4, b=−0.7, c=−0.4, d=+0.7 |
| | Zero | 13 18 | 6.7 | 20 30 | 0.7 | 13 18 | 6.7 | 20 30 | 0.7 | |
| | Greatest S | 14 01 | 5.3 | 19 53 | 1.6 | 12 52 | 6.7 | 21 11 | − 0.5 | |
| **Cape Disappointment** | Greatest N | 12 04 | 7.9 | 19 13 | − 0.7 | 13 18 | 6.1 | 18 32 | 2.9 | a=+0.9, b=−0.5, c=−0.9, d=+0.5 |
| | Zero | 11 43 | 7.2 | 17 56 | 0.8 | 11 43 | 7.2 | 17 56 | 0.8 | |
| | Greatest S | 13 18 | 6.1 | 18 32 | 2.9 | 12 04 | 7.9 | 19 13 | − 0.7 | |
| **Gray's Harbor** | Greatest N | 12 07 | 9.2 | 19 01 | − 0.1 | 13 18 | 6.8 | 18 19 | 3.9 | a=+0.9, b=−0.8, c=−0.9, d=+0.8 |
| | Zero | 11 57 | 8.7 | 18 06 | 0.9 | 11 57 | 8.7 | 18 06 | 0.9 | |
| | Greatest S | 13 18 | 6.8 | 18 19 | 3.9 | 12 07 | 9.2 | 19 01 | − 0.1 | |
| **Nee-ah Harbor** | Greatest N | 12 07 | 8.0 | 19 48 | − 0.3 | 14 23 | 5.7 | 18 29 | 4.6 | a=+0.8, b=−0.5, c=−0.8, d=+0.5 |
| | Zero | 11 56 | 7.9 | 18 18 | 1.0 | 11 56 | 7.9 | 18 18 | 1.0 | |
| | Greatest S | 14 23 | 5.7 | 18 29 | 4.6 | 12 07 | 8.0 | 19 48 | − 0.3 | |
| **Sitka** | Greatest N | 12 08 | 9.5 | 19 13 | − 0.2 | 13 26 | 7.5 | 18 35 | 4.1 | a=+1.1, b=−1.1, c=−1.1, d=+1.1 |
| | Zero | 12 39 | 9.4 | 18 48 | 1.0 | 12 39 | 9.4 | 18 48 | 1.0 | |
| | Greatest S | 13 26 | 7.5 | 18 35 | 4.1 | 12 08 | 9.5 | 19 13 | − 0.2 | |
| **Port Townshend** | Greatest N | 14 22 | 7.1 | 22 34 | − 0.8 | 19 00 | 7.9 | 22 59 | 6.6 | a=+0.2, b=−0.5, c=−0.2, d=+0.5 |
| | Zero | 15 42 | 7.1 | 21 34 | 1.9 | 15 42 | 7.1 | 21 34 | 1.9 | |
| | Greatest S | 19 00 | 7.9 | 22 59 | 6.6 | 14 22 | 7.1 | 22 34 | − 0.8 | |
| **Port Madison** | Greatest N | 15 35 | 10.6 | 22 30 | − 1.8 | 17 30 | 11.5 | 22 58 | 6.8 | a=+0.8, b=−0.6, c=−0.8, d=+0.6 |
| | Zero | 16 43 | 10.1 | 22 50 | 3.2 | 16 43 | 10.1 | 22 50 | 3.2 | |
| | Greatest S | 17 30 | 11.5 | 22 58 | 6.8 | 15 35 | 10.6 | 22 30 | − 1.8 | |

*A tabular statement of results computed for tide-tables for charts of the western coast of the United States*—Continued.

| Place. | Moon's declination. | Moon's upper meridian passage. High water. Interval. | Height. | Low water. Interval. | Height. | Moon's lower meridian passage. High water. Interval. | Height. | Low water. Interval. | Height. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | *h. m.* | *Feet.* | *h. m.* | *Feet.* | *h. m.* | *Feet.* | *h. m.* | *Feet.* | *Feet.* |
| Shilshole Bay | Greatest N | 15 16 | 9.1 | 23 09 | — 0.8 | 18 45 | 10.2 | 23 29 | 7.5 | a=+0.4 |
| | Zero | 16 21 | 10.0 | 22 30 | 2.2 | 16 21 | 10.0 | 22 30 | 2.2 | b=—0.7 |
| | Greatest S | 18 45 | 10.2 | 23 29 | 7.5 | 15 16 | 9.1 | 23 09 | — 0.8 | c=—0.4 |
| | | | | | | | | | | d=+0.7 |
| Steilacoom | Greatest N | 16 09 | 11.1 | 23 44 | — 0.8 | 18 30 | 12.6 | 23 59 | 8.5 | a=+0.7 |
| | Zero | 17 00 | 12.9 | 23 25 | 2.6 | 17 00 | 12.9 | 23 25 | 2.6 | b=—0.9 |
| | Greatest S | 18 30 | 12.6 | 23 59 | 8.5 | 16 09 | 11.1 | 23 44 | — 0.8 | c=—0.7 |
| | | | | | | | | | | d=+0.9 |
| Semi-ah-moo Bay | Greatest N | 15 24 | 8.4 | 23 35 | — 1.4 | 19 35 | 9.0 | 24 06 | 7.5 | a=+0.4 |
| | Zero | 17 09 | 8.1 | 23 27 | 2.0 | 17 09 | 8.1 | 23 27 | 2.0 | b=—0.6 |
| | Greatest S | 19 35 | 9.0 | 24 06 | 7.5 | 15 24 | 8.4 | 23 35 | — 1.4 | c=—0.4 |
| | | | | | | | | | | d=+0.6 |

# APPENDIX No. 6.

## MODE OF FORMING BRIEF PREDICTION TIDE-TABLES. BY R. S. AVERY.

The object in forming such tables as the following has been to provide means for predicting approximately the times and heights of the high and low waters from data embracing only short series of observations. It has been found convenient to use such tables where the observations have not been sufficiently extended to allow of more elaborate treatment, and it is well to have methods suited to different cases. Only one or two years' observations were used in forming each of the following tables, which have been used in making the predictions published by the Coast Survey Office, and found to answer well.

The process followed in forming these tables is substantially the same as was given in the Coast Survey Report for 1868, but more extended. The preliminary reductions and plottings were made and the plane of reference found as there described. Then instead of classifying for only four phases of the moon we arrange for all the octants, and instead of writing the ordinates for only four positions of the moon in declination we use eight. The form of the tables that follow shows what changes from the process pursued in the article above referred to must be made in making the combinations. Further study of the subject showed that great advantages would result from increasing the number of ordinates, as is here done, especially for the moon's phases.

In making predictions by these tables, it is necessary to use rolls of paper printed in checks so arranged that the time can be most conveniently written thereon horizontally, and the intervals and heights vertically, as ordinates to curves. Then having marked the places, in mean local civil time, of the moon's declination, positions and phases, reduced from the times given in the Nautical Almanac, and advanced to the right by the amount of the mean limitidal interval, plot the ordinates given in the table for the moon-declination curves, and draw them lightly with a pencil. Then lay down the moon's phases in the same way, but the values given in the tables for the phases must be treated as corrections, and laid off from the curves already described above or below, according to the signs prefixed to them in the table. Then new curves are to be drawn through these points with inks or more strongly with pencils.

We next write down on computation paper, conveniently ruled, the times of the moon's upper and lower transits suited to the meridian of the place, and write under them the ordinates read from our final curves obtained as above, reading these ordinates corresponding to the times of the transits. Then adding the time or interval ordinates to the times of the transits we have the predicted times, and the corresponding height ordinates are the predicted heights.

*San Diego, California.*

| Moon's declination. | Moon's upper meridian passage. | | | | Moon's lower meridian passage. | | | |
|---|---|---|---|---|---|---|---|---|
| | High water. | | Low water. | | High water. | | Low water. | |
| | Interval. | Height. | Interval. | Height. | Interval. | Height. | Interval. | Height. |
| | *h. m.* | *Feet.* | *h. m.* | *Feet.* | *h. m.* | *Feet.* | *h. m.* | *Feet.* |
| Zero, going north | 9 49 | 5.2 | 15 58 | 0.9 | 9 22 | 4.6 | 15 37 | 0.4 |
| Mid-north increasing | 9 15 | 5.6 | 16 20 | 0.2 | 9 58 | 3.8 | 15 04 | 1.5 |
| Greatest north | 9 00 | 5.7 | 16 29 | — 0.4 | 10 40 | 3.7 | 15 05 | 2.2 |
| Mid-north decreasing | 9 04 | 5.4 | 16 22 | — 0.3 | 10 24 | 4.3 | 15 34 | 1.9 |
| Zero, going south | 9 22 | 4.6 | 15 37 | 0.4 | 9 49 | 5.2 | 15 58 | 0.9 |
| Mid-south increasing | 9 58 | 3.8 | 15 04 | 1.5 | 9 15 | 5.6 | 16 20 | 0.2 |
| Greatest south | 10 40 | 3.7 | 15 05 | 2.2 | 9 00 | 5.7 | 16 29 | — 0.4 |
| Mid-south decreasing | 10 24 | 4.3 | 15 34 | 1.9 | 9 04 | 5.4 | 16 22 | — 0.3 |

*San Diego, Cal.*—Continued.

| Moon's phases. | Either meridian passage of moon. | | | |
|---|---|---|---|---|
| | High water. | | Low water. | |
| | Interval. | Height. | Interval. | Height. |
| | *m.* | *Feet.* | *m.* | *Feet.* |
| New moon | — 13 | + 0.70 | — 14 | — 0.65 |
| First octant | — 45 | — 0.15 | — 48 | + 0.15 |
| First quarter | + 13 | — 0.70 | + 14 | + 0.65 |
| Third octant | + 45 | + 0.15 | + 48 | — 0.15 |
| Full moon | — 13 | + 0.70 | — 14 | — 0.65 |
| Fifth octant | — 45 | — 0.15 | — 48 | + 0.15 |
| Third quarter | + 13 | — 0.70 | + 14 | + 0.65 |
| Seventh octant | + 45 | + 0.15 | + 48 | — 0.15 |

*Fort Point, Cal.*

| Moon's declination. | Moon's upper meridian passage. | | | | Moon's lower meridian passage. | | | |
|---|---|---|---|---|---|---|---|---|
| | High water. | | Low water. | | High water. | | Low water. | |
| | Interval. | Height. | Interval. | Height. | Interval. | Height. | Interval. | Height. |
| | *h. m.* | *Feet.* | *h. m.* | *Feet.* | *h. m.* | *Feet.* | *h. m.* | *Feet.* |
| Zero, going north | 11 50 | 5.1 | 17 37 | 1.1 | 11 29 | 4.4 | 17 07 | 0.7 |
| Mid-north increasing | 11 14 | 5.6 | 17 54 | 0.1 | 12 24 | 4.0 | 16 57 | 2.1 |
| Greatest north | 10 53 | 5.5 | 17 51 | — 0.5 | 12 55 | 4.2 | 17 11 | 2.8 |
| Mid-north decreasing | 10 56 | 5.1 | 17 31 | — 0.3 | 12 32 | 4.6 | 17 23 | 2.3 |
| Zero, going south | 11 29 | 4.4 | 17 07 | 0.7 | 11 50 | 5.1 | 17 37 | 1.1 |
| Mid-south increasing | 12 24 | 4.0 | 16 57 | 2.1 | 11 14 | 5.6 | 17 54 | 0.1 |
| Greatest south | 12 55 | 4.2 | 17 11 | 2.8 | 10 53 | 5.5 | 17 51 | — 0.5 |
| Mid-south decreasing | 12 32 | 4.6 | 17 23 | 2.3 | 10 56 | 5.1 | 17 31 | — 0.3 |

| Moon's phases. | Either meridian passage of moon. | | | |
|---|---|---|---|---|
| | High water. | | Low water. | |
| | Interval. | Height. | Interval. | Height. |
| | *m.* | *Feet.* | *m.* | *Feet.* |
| New moon | — 1 | + 0.3 | — 5 | — 0.5 |
| First octant | — 31 | .0 | — 30 | .0 |
| First quarter | + 1 | — 0.3 | + 5 | + 0.5 |
| Third octant | + 31 | .0 | + 30 | .0 |
| Full moon | — 1 | + 0.3 | — 5 | — 0.5 |
| Fifth octant | — 31 | .0 | — 30 | .0 |
| Third quarter | + 1 | — 0.3 | + 5 | + 0.5 |
| Seventh octant | + 31 | .0 | + 30 | .0 |

*Astoria, Oregon.*

| Moon's declination. | Moon's upper meridian passage. | | | | Moon's lower meridian passage. | | | |
|---|---|---|---|---|---|---|---|---|
| | High water. | | Low water. | | High water. | | Low water. | |
| | Interval. | Height. | Interval. | Height. | Interval. | Height. | Interval. | Height. |
| | *h. m.* | *Feet.* | *h. m.* | *Feet.* | *h. m.* | *Feet.* | *h. m.* | *Feet.* |
| Zero, going north ....... | 12 48 | 8. 1 | 19 23 | 1. 1 | 12 38 | 7. 2 | 19 03 | 0. 6 |
| Mid-north increasing.... | 12 22 | 8. 4 | 19 40 | − 0. 1 | 13 08 | 6. 7 | 18 39 | 1. 9 |
| Greatest north.......... | 12 05 | 8. 3 | 19 41 | − 0. 4 | 13 24 | 6. 6 | 18 36 | 2. 8 |
| Mid-north decreasing.... | 12 11 | 7. 9 | 19 25 | − 0. 2 | 13 15 | 7. 2 | 18 53 | 2. 4 |
| Zero, going south ....... | 12 38 | 7. 2 | 19 03 | 0. 6 | 12 48 | 8. 1 | 19 23 | 1. 1 |
| Mid-south increasing.... | 13 08 | 6. 7 | 18 39 | 1. 9 | 12. 22 | 8. 4 | 19 40 | − 0. 1 |
| Greatest south .......... | 13 24 | 6. 6 | 18 36 | 2. 8 | 12 05 | 8. 3 | 19 41 | − 0. 4 |
| Mid-south decreasing.... | 13 15 | 7. 2 | 18 53 | 2. 4 | 12 11 | 7. 9 | 19 25 | − 0. 2 |

| Moon's phases. | Either meridian passage of moon. | | | |
|---|---|---|---|---|
| | High water. | | Low water. | |
| | Interval. | Height. | Interval. | Height. |
| | *M.* | *Feet.* | *M.* | *Feet.* |
| New moon ............. | + 11 | + 0. 80 | + 17 | − 0. 55 |
| First octant............ | − 32 | + 0. 20 | − 30 | − 0. 10 |
| First quarter........... | − 11 | − 0. 80 | − 17 | + 0. 55 |
| Third octant............ | + 32 | − 0. 20 | + 30 | + 0. 10 |
| Full moon .............. | + 11 | + 0. 80 | + 17 | − 0. 55 |
| Fifth octant ............ | − 32 | + 0. 20 | − 30 | − 0. 10 |
| Third quarter.......... | − 11 | − 0. 80 | − 17 | + 0. 55 |
| Seventh octant.......... | + 32 | − 0. 20 | + 30 | + 0. 10 |

*Port Townshend, Washington Territory.*

| Moon's declination. | Moon's upper meridian passage. | | | | Moon's lower meridian passage. | | | |
|---|---|---|---|---|---|---|---|---|
| | High water. | | Low water. | | High water. | | Low water. | |
| | Interval. | Height. | Interval. | Height. | Interval. | Height. | Interval. | Height. |
| | *h. m.* | *Feet.* | *h. m.* | *Feet.* | *h. m.* | *Feet.* | *h. m.* | *Feet.* |
| Zero, going north ....... | 15 53 | 8. 2 | 21 50 | 2. 8 | 15 15 | 6. 4 | 21 17 | 0. 9 |
| Mid-north increasing.... | 14 48 | 7. 8 | 22 12 | 0. 4 | 17 49 | 6. 2 | 21 12 | 5. 3 |
| Greatest north.......... | 14 22 | 7. 3 | 22 36 | − 0. 8 | 19 00 | 7. 6 | 22 58 | 6. 6 |
| Mid-north decreasing.... | 14 36 | 6. 8 | 22. 00 | − 1. 0 | 17 24 | 8. 2 | 22 25 | 5. 2 |
| Zero, going south ....... | 15 15 | 6. 4 | 21 17 | 0. 9 | 15 53 | 8. 2 | 21 50 | 2. 8 |
| Mid-south increasing.... | 17 49 | 6. 2 | 21 12 | 5. 3 | 14 48 | 7. 8 | 22 12 | 0. 4 |
| Greatest south.......... | 19 00 | 7. 6 | 22 58 | 6. 6 | 14 22 | 7. 3 | 22 36 | − 0. 8 |
| Mid-south decreasing.... | 17 24 | 8. 2 | 22 25 | 5. 2 | 14 36 | 6. 8 | 22 00 | − 1. 0 |

*Port Townshend, W. T.*—Continued.

| Moon's phases. | Either meridian passage of moon. | | | |
|---|---|---|---|---|
| | High water. | | Low water. | |
| | Interval. | Height. | Interval. | Height. |
| | *m.* | *Feet.* | *m.* | *Feet.* |
| New moon | − 15 | + 0.20 | − 4 | − 0.55 |
| First octant | − 34 | − 0.15 | − 38 | − 0.10 |
| First quarter | + 15 | − 0.20 | + 4 | + 0.55 |
| Third octant | + 34 | + 0.15 | + 38 | + 0.10 |
| Full moon | − 15 | + 0.20 | − 4 | − 0.55 |
| Fifth octant | − 34 | − 0.15 | − 38 | − 0.10 |
| Third quarter | + 15 | − 0.20 | + 4 | + 0.55 |
| Seventh octant | + 34 | + 0.15 | + 38 | + 0.10 |

*Key West, Florida.*

| Moon's declination. | Moon's upper meridian passage. | | | | Moon's lower meridian passage. | | | |
|---|---|---|---|---|---|---|---|---|
| | High water. | | Low water. | | High water. | | Low water. | |
| | Interval. | Height. | Interval. | Height. | Interval. | Height. | Interval. | Height. |
| | *h. m.* | *Feet.* | *h. m.* | *Feet.* | *h. m.* | *Feet.* | *h. m.* | *Feet.* |
| Zero, going north | 9 43 | 1.55 | 15 03 | 0.30 | 9 39 | 1.60 | 15 10 | 0.20 |
| Mid-north, increasing | 10 07 | 1.15 | 14 23 | 0.50 | 9 03 | 1.90 | 15 44 | −0.10 |
| Greatest north | 10 30 | 0.90 | 13 55 | 0.60 | 8 48 | 1.90 | 15 53 | −0.15 |
| Mid-north, decreasing | 10 20 | 1.05 | 14 22 | 0.55 | 9 10 | 1.80 | 15 38 | 0.00 |
| Zero, going south | 9 39 | 1.60 | 15 10 | 0.20 | 9 43 | 1.55 | 15 03 | 0.30 |
| Mid-south, increasing | 9 03 | 1.90 | 15 44 | −0.10 | 10 07 | 1.15 | 14 23 | 0.50 |
| Greatest south | 8 48 | 1.90 | 15 53 | −0.15 | 10 30 | 0.90 | 13 55 | 0.60 |
| Mid-south, decreasing | 9 10 | 1.80 | 15 38 | 0.00 | 10 20 | 1.05 | 14 22 | 0.55 |

| Moon's phases. | Either meridian passage of moon. | | | |
|---|---|---|---|---|
| | High water. | | Low water. | |
| | Interval. | Height. | Interval. | Height. |
| | *m.* | *Feet.* | *m.* | *Feet.* |
| New moon | + 7 | +0.20 | + 6 | −0.15 |
| First octant | −43 | 0.00 | −34 | −0.05 |
| First quarter | − 7 | −0.20 | − 6 | +0.15 |
| Third octant | +43 | 0.00 | +34 | +0.05 |
| Full moon | + 7 | +0.20 | + 6 | −0.15 |
| Fifth octant | −43 | 0.00 | −34 | −0.05 |
| Third quarter | − 7 | −0.20 | − 6 | +0.15 |
| Seventh octant | +43 | 0.00 | +34 | +0.05 |

*Fort Clinch, Fernandina, Florida.*

| Moon's declination. | Moon's upper meridian passage. | | | | Moon's lower meridian passage. | | | |
|---|---|---|---|---|---|---|---|---|
| | High water. | | Low water. | | High water. | | Low water. | |
| | Interval. | Height. | Interval. | Height. | Interval. | Height. | Interval. | Height. |
| | *h. m.* | *Feet.* | *h. m.* | *Feet.* | *h. m.* | *Feet.* | *h. m.* | *Feet.* |
| Zero, going north | 7 53 | 6. 36 | 14 04 | 0. 23 | 7 48 | 6. 26 | 13 58 | −0. 05 |
| Mid-north, increasing | 7 54 | 6. 71 | 14 15 | 0. 41 | 7 52 | 5. 74 | 13 50 | −0. 12 |
| Greatest north | 7 48 | 6. 80 | 14 14 | 0. 35 | 7 42 | 5. 48 | 13 46 | 0. 00 |
| Mid-north, decreasing | 7 43 | 6. 65 | 14 07 | 0. 19 | 7 45 | 5. 64 | 13 46 | 0. 15 |
| Zero, going south | 7 48 | 6. 26 | 13 58 | −0. 05 | 7 53 | 6. 36 | 14 04 | 0. 23 |
| Mid-south, increasing | 7 52 | 5. 74 | 13 50 | −0. 12 | 7 54 | 6. 71 | 14 15 | 0. 41 |
| Greatest south | 7 42 | 5. 48 | 13 46 | 0. 00 | 7 48 | 6. 80 | 14 14 | 0. 35 |
| Mid-south, decreasing | 7 45 | 5. 64 | 13 46 | 0. 15 | 7 43 | 6. 65 | 14 07 | 0. 19 |

| Moon's phases. | Either meridian passage of moon. | | | |
|---|---|---|---|---|
| | High water. | | Low water. | |
| | Interval. | Height. | Interval. | Height. |
| | *m.* | *Feet.* | *m.* | *Feet.* |
| New moon | +11 | +0. 47 | +11 | −0. 47 |
| First octant | −19 | +0. 16 | −21 | +0. 02 |
| First quarter | −11 | −0. 47 | −11 | +0. 47 |
| Third octant | +19 | −0. 16 | +21 | −0. 02 |
| Full moon | +11 | +0. 47 | +11 | −0. 47 |
| Fifth octant | −19 | +0. 16 | −21 | +0. 02 |
| Third quarter | −11 | −0. 47 | −11 | +0. 47 |
| Seventh octant | +19 | −0. 16 | +21 | −0. 02 |

# APPENDIX No. 7.

REPORT ON THE LEVELING OPERATIONS BETWEEN KEYPORT, ON RARITAN BAY, AND GLOUCESTER, ON THE DELAWARE RIVER, TO DETERMINE THE HEIGHT ABOVE MEAN TIDE OF THE PRIMARY STATIONS BEACON HILL, DISBOROUGH, STONY HILL, MOUNT HOLLY, AND PINE HILL. BY RICHARD D. CUTTS, ASSISTANT COAST SURVEY, IN CHARGE OF SECONDARY TRIANGULATION.

## HEIGHTS ABOVE MEAN TIDE DETERMINED BY THE SPIRIT-LEVEL.

The leveling was executed in 1870, by Charles Ferguson, esq., Sub-assistant United States Coast Survey.

The line started from mean tide at Keyport, on Raritan Bay, and, following the route most convenient for determining the height of the primary stations, ended at mean tide of the Delaware River at Gloucester City. The route pursued was not, therefore, the most direct, the one preferred being that on which the longest extent of turnpike and railroad track could be made available. The length of the main line was seventy-seven miles, and of the offsets, thirteen miles; the total distance leveled and releveled, one section after the other, being one hundred and eighty miles.

The observations are contained in ten volumes. These latter will show the different sections into which the main line was divided; the offsets to the triangulation stations Beacon Hill, Disborough, Stony Hill, and Mount Holly; also, the offsets to the barometer stations; and, finally, the height above mean tide of the bench-marks established at the villages through which the line passed.

An additional line of levels was run in 1871 by Mr. B. A. Colonna, aid United States Coast Survey, to connect the triangulation and barometer station Pine Hill with the bench-mark at Gloucester City.

### TIDAL STATIONS.

A tide-staff was set up at Keyport and another at Gloucester City, and the tides were observed at each station during a half-lunation, for the purpose of determining the level of mean tide. This level, or the computed half-tide mark on the staff, was then transferred to a permanent bench-mark established in the vicinity of each tide-gauge—these two bench-marks being the termini of the line of levels.

### INSTRUMENTS.

The instrument used was a pivot-level made by Wurdemann. The telescope possessed a magnifying power of 30, was provided with a reticule of three fixed horizontal wires about 4′ apart, and of two vertical wires, and with a riding-level, a division of which represented 3″ in arc at the average temperature at which the instrument would be used in the field.

The leveling-rod was made of seasoned Honduras mahogany and painted white; was $3^{m}.2$ in length by $0^{m}.06$ in width and $0^{m}.04$ in thickness, and was provided with a wooden handle attached to the back part, about 5.6 feet above the bottom, and by means of which the rod could be carried and held in position, and with two small levels, fixed at right angles, to secure its verticality. To prevent displacement, or change of level when the rod was turned round for the back sight, the foot of the rod, incased in brass, terminated in a cylindrical button, fitted to and moving freely in the socket of the iron foot-plate on which it rested. This plate, six inches in diameter, was armed underneath with sharp-pointed legs, so that when it was dropped by the rod-man on reaching his station, it could be firmly planted in the ground by a stamp or two of the foot. A light chain, with a ring as a handle, was attached to the plate, by which the latter could be readily taken up and carried forward by the rod-man. Three of such rods and foot-plates accompanied the leveling-instrument, two sets for constant use and the other held as a reserve.

The rods were divided to centimeters, the divisions and comparisons having been made at the Coast Survey Office in Washington.

FIELD OBSERVATIONS AND RECORDS.

The first operation consisted in determining the values of the instrumental constants, viz:

1. Of a division of the level;
2. Of the angular distance between the horizontal wires; and
3. Of the reduction of the mean of the three wires to the middle wire.

By means of these constants, tables were made out which gave, by inspection:

A.—The distance of the instrument to the rod;

B.—The correction to reduce the mean of the three wires to the middle wire;

C.—The correction on account of the want of level at the moment of observation, and of the daily recorded instrumental errors; and

D.—The correction for difference of distance between the back and fore sights.

The order in which the observations were made and recorded, and the directions followed in conducting the operation, may be stated as follows:

I.—An adjustment of the instrument, either complete or closely approximate, with all the details duly entered in the record.

This adjustment was made at the commencement and end of each day's work, and consisted:

*a*—in making the axis of the level parallel with the optical axis of the telescope;

*b*—in making the axis of the level perpendicular to the vertical axis of the instrument; and

*c*—in bringing the middle horizontal wire and the middle of the two vertical wires in the optical axis of the telescope.

When this adjustment was approximate only, Tables B and C enabled the computer to apply the necessary corrections to the results of the day's leveling.

II.—The placing of the instrument midway, and, if possible, in line between the two rods. In cases where the distance between the back and fore sights was necessarily or by accident unequal, as shown by the recorded differences between the extreme wires, Tables D supplied the correction to be applied on account of the resulting inequality of curvature and refraction.

III.—The protection of the instrument from the direct rays of the sun by a cap when carried and an umbrella when in use.

IV.—The adjustment for verticality of axis; of the focus for distinct vision; of the bubble to the middle of the tube and the recording of the divisions as shown by the eye and object ends; the reading of the heights on the rod crossed by the three wires, and the second reading and recording of the level bubble. Table C supplied the correction for the difference between the readings of the two ends of the bubble.

V.—Bench-marks were established at the end of each day's work, at the different villages through which the line was carried, and whenever from any cause the leveling was suspended.

The details of the work were carried out in conformity with the order and principles contained in instructions specially prepared for the instrument used and the object in view, under the four following headings:

1. Tide-gauge, records, and tidal-station or bench-mark.
2. Adjustment of the instrument.
3. Formulæ, constants, and corrections.
4. General directions for running a line of levels.

The re-leveling was required not merely for the sake of verification, but for precision, as it is a well-established fact that there will be always a difference, irrespective of instrumental and personal errors, between the results obtained by the leveling of a line in one direction, and then back again to the starting point.

The heights will be given, in all cases, above the mean tide of Raritan Bay; the description of the principal bench-marks is given in the records.

The revised results will be published in the next annual report.

# APPENDIX No. 8.

REPORT ON RESULTS OF THE BAROMETRICAL OBSERVATIONS MADE, IN CONNECTION WITH THE LINE OF SPIRIT-LEVELING FROM RARITAN BAY TO THE DELAWARE RIVER, TO DETERMINE THE HEIGHTS ABOVE MEAN TIDE OF THE PRIMARY STATIONS MOUNT HOLLY, STONY HILL, PINE HILL, MOUNT ROSE, NEWTOWN, WILLOW GROVE, GARD, BETHEL, AND LIPPINCOTT. BY RICHARD D. CUTTS, ASSISTANT COAST SURVEY, IN CHARGE OF SECONDARY TRIANGULATION.

## DIFFERENCES OF ALTITUDE DETERMINED BY THE CISTERN BAROMETER.

The observers were F. H. Agnew, sub-assistant; Edwin Smith, B. A. Colonna, and Charles L. Gardner, aids, United States Coast Survey, and Mr. Charles F. Wurdemann, and it is to their care and interest in every detail that the success of the operation is principally due.

The barometers and psychrometers were made specially for the purpose by James Green, esq., of New York, and were of the most approved and delicate construction. The diameters of the barometer tubes were, respectively, 0.27, 0.28, 0.29, and 0.30 of an inch. The correction for capillarity was made on the scale. In this connection it may be mentioned that the instruments were carefully compared with the standard, although intended for the determination of differences and not of absolute heights.

The party was organized at Mount Holly, New Jersey, early in July, and commenced at once the necessary practice, following certain prescribed rules derived from the Smithsonian pamphlet and other authorities.

The instrumental errors and the personal equations of the observers were determined by careful comparisons made before, during, and after the observations in the field, the observers returning with their instruments to Mount Holly for the purpose.

The hours selected for the observations were those which have been found by experience to represent very nearly the mean of the twenty-four hours, viz: 7 a. m .and 2 and 9 p. m.; or those at which the equilibrium of temperature is the most thoroughly established, as at two hours after sunrise and about the time of sunset; or 9 a. m. and 9 p. m. when the mercurial column would be equally too high and too low.

The observations were not made at the triangulation station, but at the house nearest thereto at which the necessary accommodations and facilities could be found; and the difference of height between the surface of the mercury (or the barometrical station) and the bench-mark or stub at the triangulation station was determined by the spirit-level, the line being leveled, as usual, in both directions.

Every precaution was taken to secure uniformity of conditions at all the stations. The latticed frames for the dry and wet-bulb thermometers were alike in all respects, and were attached, in each case, to the outside frame of a north window, second story, of the house occupied by the observer. The barometer was suspended inside, and one window of the room was always left open.

## COMPARISON OF INSTRUMENTS AND THE DETERMINATION OF PERSONAL ERRORS.

All the comparisons were made in the parlor of Sharpe's house, Mount Holly. The barometers and thermometers were suspended from hooks screwed into a large rack made for the purpose; were placed about one foot apart, at the same height, and always in the same relative position, and he observations were made at the same temperature and under other similar conditions.

I.—*Comparison of attached thermometers.*

| Date of comparison. | No. of thermometer. | F. H. Agnew. | | B. A. Colonna. | | C. L. Gardner. | | E. Smith. | | C. F. Wurdemann. | | Mean. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Observations. | Difference. | Observations. | Difference. | Observations. | Difference. | Observations. | Difference. | Observations. | Difference. | Observations. | Difference. |
| | | *No.* | ° | *No.* | ° | *No.* | ° | *No.* | ° | *No.* | ° | *No.* | ° |
| July 9 to 16 | 1730 | 10 | 0.00 | 17 | 0.00 | 23 | 0.00 | 13 | 0.00 | ...... | ............ | 63 | 0.00 |
| | 1735 | 10 | — .27 | 17 | — .17 | 23 | — .09 | 13 | — .19 | ...... | ............ | 63 | — .18 |
| | 1738 | 10 | — .24 | 17 | — .16 | 23 | — .12 | 13 | — .18 | ...... | ............ | 63 | — .18 |
| | 1739 | 10 | — .26 | 17 | — .15 | 23 | — .16 | 13 | — .17 | ...... | ............ | 63 | — .18 |
| August 5 to 8 | 1730 | 9 | 0.00 | 9 | 0.00 | 10 | 0.00 | 11 | 0.00 | ...... | ............ | 39 | 0.00 |
| | 1735 | 9 | — .34 | 9 | — .21 | 10 | — .31 | 11 | — .13 | ...... | ............ | 39 | — .25 |
| | 1738 | 9 | — .31 | 9 | — .23 | 10 | — .32 | 11 | — .13 | ...... | ............ | 39 | — .25 |
| | 1739 | 9 | — .33 | 9 | — .23 | 10 | — .31 | 11 | — .10 | ...... | ............ | 39 | — .25 |
| September 12 and 13 | 1730 | ...... | ............ | 10 | 0.00 | 10 | 0.00 | 10 | 0.00 | 10 | 0.00 | 40 | 0.00 |
| | 1735 | ...... | ............ | 10 | — .07 | 10 | — .04 | 10 | — .12 | 10 | + .04 | 40 | — .05 |
| | 1738 | ...... | ............ | 10 | — .08 | 10 | — .15 | 10 | — .15 | 10 | .00 | 40 | — .09 |
| | 1739 | ...... | ............ | 10 | — .09 | 10 | — .21 | 10 | — .17 | 10 | —.04 | 40 | — .13 |

Table I gives the results of the comparisons made for determining the difference between the attached thermometers. The thermometers were read, one after the other, by each observer, and a second comparison made after an interval sufficient to permit the mercury to recover from the temporary effect of the heat transmitted from the observer's body. The number of such comparisons by each observer is given in the table, and the regularity of the mean differences at any one date is proof of the correctness of the observations.

These comparisons show that No. 1730 differed from the other three, at each comparison, by a nearly uniform quantity, and as there is a greater probability that the temperature as generally indicated by the attached thermometer is rather higher than lower than that of the mercury in the cistern and tube, the difference is subtracted from 1730, so that all four may read alike. For the correction to be applied to the observations taken in the field between the comparisons of July and August, the mean 0°.21 of the differences would be preferred, and, similarly, 0°.17 for the observations between the comparisons of August and September. As these two means, however, are so nearly alike, and certainly within the personal errors of the observers, we have adopted the uniform quantity of 0°.2 as the correction to be subtracted from the thermometer attached to barometer No. 1730.

The comparisons between the different dry and wet bulbs showed unimportant differences, considering the slight differences of elevation between the stations.

The subjoined table contains the comparisons made to determine the differences existing between the different barometers. The adjustments of the mercury in the cistern and of the vernier to the height of the column were made immediately after observing the attached thermometers, each observer adjusting the four barometers, one after the other, and then reading them. The comparison was repeated at stated intervals, and, in every instance, the tube was inclined and the mercury and vernier re-adjusted.

The relative instrumental differences at each date of the series of comparisons are nearly the same, while the quantities differ from one date to the other by an average of .0015 of an inch, a variation which would appear to be principally due to changes in No. 1730. These differences, however, do not include the personal error of the observers, and are not, therefore, the proper corrections to be applied to the field observations. One observer may adjust or read too high, and another too low, and the resulting difference may either largely increase or entirely neutralize the instrumental error recorded in Table II.

II.—*Comparison of barometers.*

| Date. | No. of barometer. | F. H. Agnew. | | B. A. Colonna. | | C. L. Gardner. | | Edwin Smith. | | Ch.F.Wurdemann. | | Mean. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Observations. | Difference. | Observations. | Difference. | Observations. | Difference. | Observations. | Difference. | Observations. | Difference. | Observations. | Difference. |
| | | *No.* | ° | *No.* | ° | *No.* | ° | *No.* | ° | *No.* | ° | *No.* | ° |
| July 9 to 16 | 1730 | 16 | 0.0000 | 18 | 0.0000 | 24 | 0.0000 | 30 | 0.0000 | ...... | ............ | 88 | 0.0000 |
| | 1735 | 16 | + .0035 | 18 | + .0023 | 24 | + .0027 | 30 | + .0027 | ...... | ............ | 88 | + .0028 |
| | 1738 | 16 | + .0033 | 18 | + .0021 | 24 | + .0030 | 30 | + .0028 | ...... | ............ | 88 | + .0028 |
| | 1739 | 16 | + .0009 | 18 | + .0001 | 24 | + .0006 | 30 | + .0006 | ...... | ............ | 88 | + .0005 |
| August 5 to 8 | 1730 | 9 | 0.0000 | 9 | 0.0000 | 11 | 0.0000 | 11 | 0.0000 | ...... | ............ | 40 | 0.0000 |
| | 1735 | 9 | + .0036 | 9 | + .0056 | 11 | + .0035 | 11 | + .0041 | ...... | ............ | 40 | + .0042 |
| | 1738 | 9 | + .0035 | 9 | + .0055 | 11 | + .0039 | 11 | + .0044 | ...... | ............ | 40 | + .0043 |
| | 1739 | 9 | + .0009 | 9 | + .0013 | 11 | + .0008 | 11 | + .0019 | ...... | ............ | 40 | + .0012 |
| September 12 and 13. | 1730 | ...... | ............ | 10 | 0.0000 | 10 | 0.0000 | 10 | 0.0000 | 10 | 0.0000 | 40 | 0.0000 |
| | 1735 | ...... | ............ | 10 | +0.0079 | 10 | + .0058 | 10 | + .0063 | 10 | + .0066 | 40 | + .0067 |
| | 1738 | ...... | ............ | 10 | + .0074 | 10 | + .0059 | 10 | + .0055 | 10 | + .0059 | 40 | + .0062 |
| | 1739 | ...... | ............ | 10 | + .0026 | 10 | + .0013 | 10 | + .0023 | 10 | + .0026 | 40 | + .0022 |

III.—*Observations to determine the personal error of the observers.*

| August 9, 1870. | F. H. Agnew. | B. A. Colonna. | C. L. Gardner. | E. Smith. | September 14, 1870. | Ch. Wurdemann. | B. A. Colonna. | C. L. Gardner. | E. Smith. |
|---|---|---|---|---|---|---|---|---|---|
| | 1730. | 1735. | 1738. | 1739. | | 1730. | 1735. | 1738. | 1739. |
| *h. m.* | | | | | *h. m.* | | | | |
| 9.40 a. m | 30.204 | 30.207 | 30.209 | 30.208 | 6.35 a. m | 30.366 | 30.374 | 30.370 | 30.370 |
| 10.20 a. m | .205 | .209 | .208 | .208 | 6.48 a. m | .365 | .374 | .368 | .366 |
| 10.45 a. m | .200 | .206 | .202 | .201 | 7.00 a. m | .364 | .370 | .366 | .364 |
| 11.05 a. m | .197 | .202 | .198 | .200 | 7.14 a. m | .364 | .368 | .364 | .364 |
| 11.35 a. m | .189 | .195 | .192 | .193 | 7.25 a. m | .364 | .370 | .364 | .364 |
| 12.00 m | .182 | .188 | .188 | .186 | 8.16 a. m | .364 | .376 | .368 | .368 |
| 0.27 p. m | .175 | .181 | .180 | .180 | 8.30 a. m | .374 | .380 | .375 | .374 |
| 0.50 p. m | .168 | .176 | .172 | .173 | 8.43 a. m | .382 | .387 | .384 | .384 |
| 2.40 p. m | .149 | .154 | .154 | .150 | 8.55 a. m | .386 | .396 | .391 | .389 |
| 3.10 p. m | .146 | .149 | .146 | .147 | 9.08 a. m | .388 | .394 | .394 | .390 |
| 3.20 p. m | .142 | .149 | .145 | .144 | 9.20 a. m | .388 | .396 | .394 | .392 |
| 3.35 p. m | .137 | .143 | .142 | .140 | 9.32 a. m | .389 | .396 | .397 | .394 |
| 3.50 p. m | .130 | .136 | .136 | .135 | 9.45 a. m | .389 | .393 | .396 | .392 |
| 4.00 p. m | .132 | .136 | .134 | .133 | 10.00 a. m | .392 | .398 | .396 | .396 |
| 4.15 p. m | .125 | .130 | .131 | .128 | 10.14 a. m | .392 | .397 | .400 | .396 |
| 4.30 p. m | .131 | .136 | .136 | .135 | 10.27 a. m | .392 | .394 | .396 | .393 |
| 4.45 p. m | .132 | .139 | .138 | .136 | 10.40 a. m | .391 | .388 | .390 | .388 |
| 5.00 p. m | .136 | .144 | .140 | .139 | 10.53 a. m | .381 | .387 | .388 | .384 |
| 5.15 p. m | .136 | .144 | .142 | .140 | 11.05 a. m | .376 | .384 | .383 | .381 |
| 5.30 p. m | 30.140 | 30.147 | 30.146 | 30.142 | 11.18 a. m | 30.374 | 30.380 | 30.379 | 30.378 |
| | 30.1578 | 30.1635 | 30.1619 | 30.1609 | | 30.3791 | 30.3851 | 30.3831 | 30.3813 |
| Correction for 0°.2. | —.0005 | | | | | — .0005 | | | |
| | 30.1573 | | | | | 30.3786 | | | |

The observations recorded in Table III were made simultaneously, each observer confining himself to his own instrument. By this means, a combination of both errors, instrumental and personal, was obtained. The table, therefore, gives the true differences to be used in comparing corresponding observations by any two observers in order to reduce them to the same standard.

The attached thermometers were observed before the barometers were adjusted, but as it was upon trial that the sensitiveness of the thermometers from the proximity of the person of the observer was so much greater than that of the mercury in the barometer from the same cause, a correction of the recorded heights on account of the slight differences of temperature exhibited by the attached thermometers would produce a greater error in the above comparisons than its omission. As previously stated, the conditions in regard to height, air, and light under which all the comparisons were made, were precisely alike for each instrument.

It will be seen that, for the sake of convenience, the plus error 0°.2 of the thermometer attached to barometer 1730, has been combined with the instrumental and personal error of that barometer and observer, and the correction applied, once for all.

IV.—*Table showing the stations occupied by the different barometers, and the correction to be applied to the observations at each station, according to the date at which they were taken.*

| Number of the barometer. | Number of comparisons. | Between July 20 and August 25. | | Between August 27 and September 9. | |
|---|---|---|---|---|---|
| | | Stations. | Correction. | Stations. | Correction. |
| 1730 | 20 | Mount Holly | .0000 | Bethel | .0000 |
| 1735 | 20 | Mount Rose, Gloucester City | —.0062 | Gloucester City | —.0065 |
| 1738 | 20 | Newtown, Willow Grove | —.0046 | Yard | —.0045 |
| 1739 | 20 | Stony Hill, Pine Hill | —.0036 | Lippincott | —.0027 |

Each observer retained the same instruments, and the same observers were employed in groups A and B. Before group C was commenced Mr. Agnew left and Mr. Wurdemann took his place, introducing another personal equation. The combined corrections resulting from the comparisons of August 9 have been, therefore, applied to the observations taken at the stations in groups A and B, and those from the comparisons of September 14 to the observations belonging to group C.

The mean effect on any single result for a difference of height, caused by an error of adjustment or reading, may be stated as follows:

| | In. | Feet. |
|---|---|---|
| Barometer, error of | .001 | 1.01 |
| Attached thermometer, error of | 1°.0 | 2.60 |
| Dry bulb, error of | 1°.0 | 0.22 |
| Wet bulb, error of | 1°.0 | 0.04 |

The records will show how improbable it is that any such errors as the three last have been committed. Should occasional instances have occurred, however, the errors would be hardly appreciable in the general mean.

FIELD RECORD.

The comparisons having been completed and the watches compared and rated, the observers started for their respective stations, each with instructions in regard to the transportation and setting up of his instruments, and to the order and care into which the details of each observation should be carried out.

As a security against errors of adjustment or reading, these observations, each one complete in itself, were taken at intervals of five minutes, the mean of which constituted the observation for the hour, as shown in the following transcript from the field-book:

*Mount Holly barometer-station, Thursday, July 21, 1870.*

| Time. | Dry bulb. | Wet bulb. | Attached thermometer. | Barometer. | Mean. | Reduced to 32° Fahr. | Remarks, weather, &c. |
|---|---|---|---|---|---|---|---|
| *h. m.* | ° | ° | | | | | |
| 6.55 a. m...... | 72.0 | 70.0 | 78.2 | 30.026 | | | |
| 7.00 a. m...... | 72.1 | 70.1 | 78.5 | .027 | 30.0260 | 29.8919 | Clouds 8; calm. Some rain during the latter part of the night. |
| 7.05 a. m...... | 72.2 | 70.2 | 78.7 | .025 | | | |
| | 72.10 | 70.10 | 78.47 | | | | |
| 8.55 a. m...... | 76.6 | 72.5 | 78.5 | 30.042 | | | |
| 9.00 a. m...... | 77.0 | 73.0 | 78.8 | .039 | 30.0410 | 29.9062 | Clear; wind light from W. N. W. |
| 9.05 a. m...... | 77.3 | 73.2 | 79.1 | .042 | | | |
| | 76.97 | 72.90 | 78.80 | | | | |
| 1.55 p. m...... | 86.0 | 74.0 | 84.5 | 30.066 | | | |
| 2.00 p. m...... | 86.0 | 73.8 | 84.5 | .065 | 30.0653 | 29.9151 | Clear; wind light from N. W. |
| 2.05 p. m...... | 86.0 | 74.0 | 84.4 | .065 | | | |
| | 86.00 | 73.93 | 84.47 | | | | |
| 6.55 p. m...... | 81.7 | 75.5 | 84.3 | 30.061 | | | |
| 7.00 p. m...... | 80.9 | 75.2 | 84.3 | .060 | 30.0603 | 29.9105 | Clear and calm. |
| 7.05 p. m...... | 80.4 | 75.0 | 84.3 | .060 | | | |
| | 81.00 | 75.23 | 84.30 | | | | |
| 8.55 p. m...... | 77.3 | 72.7 | 81.5 | 30.090 | | | |
| 9.00 p. m...... | 77.2 | 72.7 | 81.8 | .091 | 30.0913 | 29.9482 | Clear and calm. |
| 9.05 p. m...... | 77.0 | 72.5 | 82.2 | .093 | | | |
| | 77.17 | 72.63 | 81.83 | | | | |
| Mean......... | 78.65 | 72.96 | 81.57 | 30.0568 | 30.0568 | 29.9146 | |

THE COMPUTATIONS.

The difference in altitude in no case exceeded 387 feet, nor was the distance between any two stations greater than twenty-five and one-fourth miles. The country embraced within the field of operations was comparatively level, and the observations in each group were taken simultaneously and at a season the most favorable for uniformity in the atmospheric pressure. Under these circumstances, the observations which were made at corresponding stations have been used for determining differences of height without regard to the possibility of there being a difference in the hourly oscillation of the barometer and thermometer at the two stations.

If, however, we had adopted the Philadelphia table of hourly corrections, supposing them to be constant for the country and climate within a radius of forty miles of Girard College, the differences in height deduced from the original and corrected observations would have been identical for the reason that the corrections being applied to the same hours at both stations, would neutralize each other. Hence, in order to make any such corrections really effective, in the case of simultaneous observations, it is necessary that the amplitude of the diurnal oscillation at one station should differ from that at the corresponding station. If we now employ the observations themselves to determine the hourly variation at each station, we obtain a series of tables in which the correction for each hour is different, the differences ranging from .0002 to .008 of an inch. The application of these corrections would change the results for the different hours but not the general mean, while on the other hand the results would be less harmonious.

In the absence, therefore, of any extended series of observations at the different stations, the hourly oscillation has been assumed to be the same for each group and date, while the more important requirements, which were really within our control, of observing at the same moment of time and at hours representing the daily mean, were strictly fulfilled. The correctness of the above assumption is confirmed by the fact that the mean of the five hours does not differ from the mean of the hours of 7 a. m. and 2 and 9 p. m.—taking the average of fifteen separate series—by more than $0^m.15$, the greatest difference being equivalent to .001 of an inch in the reading of the barometric column.

For the computations, we have adopted Bessel's formula and Plantamour's tables, as given by Guyot in his "Meteorological and Physical Tables prepared for the Smithsonian Institute," pages 72 to 80, series D. In regard, however, to the observations at present under discussion, it may be stated that the resulting differences of height would be nearly the same, (in no case differing more than 15 inches,) whether they were obtained by the formula and tables of LaPlace and Guyot, or by those of Bessel and Plantamour or Ruhlmann.

Tables V to XXII, inclusive, give the observations (reduced to the freezing point and corrected for instrumental errors and personal equation) at the corresponding stations in each group, and the computed differences of altitude.

V.—*Difference of height between the barometer-stations of Mount Holly and Stony Hill, by comparison of the hourly means.*

| Hour. | No. of daily observations. | Mount Holly. | | | Stony Hill. | | | Difference in height. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Dry bulb. | Wet bulb. | Barometer at 32°, + .0036. | Dry bulb. | Wet bulb. | Barometer at 32°. | Meters. | Mean. | Variation from mean. | Probable error. |
| | | ° | ° | | ° | ° | | | | | |
| 7.00 a. m | 11 | 73.35 | 69.34 | 29.9446 | 73.36 | 68.82 | 29.7819 | 47.66 | ....... | 0.25 | |
| 9.00 a. m | 11 | 77.72 | 70.69 | .9537 | 77.27 | 70.28 | .7916 | 47.83 | ....... | 0.42 | |
| 2.00 p. m | 11 | 85.60 | 72.21 | .9308 | 84.08 | 70.70 | .7704 | 47.97 | 47.41 | 0.56 | ± 0.39 |
| 7.00 p. m | 11 | 79.88 | 72.34 | .9128 | 79.02 | 70.85 | .7548 | 46.95 | ....... | 0.46 | |
| 9.00 p. m | 11 | 76.35 | 70.97 | .9328 | 76.22 | 69.86 | .7745 | 46.65 | ....... | 0.76 | |
| Mean of hours 7 a. m. 2 and 9 p. m | | | | | | | | | 47.43 | | |
| Probable error of result | | | | | | | | | | | ± 0.17 |

VI.—*Difference of height between the barometer-stations of Mount Holly and Stony Hill, by comparison of the daily means, or mean of the 7 a. m., 2 p. m., and 9 p. m. observations.*

| Date. | No. of daily observations. | Mount Holly. | | | Stony Hill. | | | Difference of height. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Dry bulb. | Wet bulb. | Barometer at 32°, + .0036. | Dry bulb. | Wet bulb. | Barometer at 32°. | Meters. | Mean. | Variation from mean. | Probable error. |
| | | ° | ° | | ° | ° | | | | | |
| July 21 | 3 | 78.42 | 72.22 | 29.9219 | 77.51 | 70.79 | 29.7650 | 46.41 | ....... | 1.02 | |
| 22 | 3 | 75.65 | 67.02 | 30.0444 | 75.06 | 66.17 | .8852 | 46.59 | ....... | 0.84 | |
| 23 | 3 | 80.71 | 74.01 | .0449 | 79.88 | 73.80 | .8849 | 47.38 | ....... | 0.05 | |
| 25 | 3 | 83.34 | 75.34 | 29.9690 | 83.12 | 74.06 | .8083 | 47.96 | ....... | 0.53 | |
| 26 | 3 | 82.63 | 72.67 | .9539 | 82.14 | 72.04 | .7931 | 47.89 | ....... | 0.46 | |
| 27 | 3 | 81.22 | 73.16 | .8999 | 76.13 | 71.50 | .7434 | 46.40 | 47.43 | 1.03 | ± 0.57 |
| 28 | 3 | 77.98 | 73.63 | .8615 | 76.89 | 73.03 | .7043 | 46.59 | ....... | 0.84 | |
| 29 | 3 | 76.40 | 69.96 | .7906 | 77.45 | 68.98 | .6260 | 48.78 | ....... | 1.35 | |
| 30 | 3 | 70.52 | 62.65 | 30.0053 | 70.81 | 61.76 | .8394 | 48.14 | ....... | 0.71 | |
| Aug. 1 | 3 | 75.76 | 66.66 | 29.9455 | 75.56 | 65.52 | .7845 | 47.28 | ....... | 0.15 | |
| 2 | 3 | 79.39 | 74.89 | .8599 | 78.83 | 70.27 | .6973 | 48.32 | ....... | 0.89 | |
| Probable error of result | | | | | | | | | | | ± 0.17 |

### VII.—*Height of Mount Rose barometer-station, from hourly means.*

| Hour. | No. of daily observations. | Mount Rose barometer-station. | | | Mount Holly barometer-station. | | | Stony Hill barometer-station. | | | Mount Rose above— | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | Mount Holly. | | Stony Hill. | |
| | | Dry bulb. | Wet bulb. | Barometer at 32°. | Dry bulb. | Wet bulb. | Barometer at 32°, +.0062. | Dry bulb. | Wet bulb. | Barometer at 32°, +.0026. | Meters. | Variation. | Meters. | Variation. |
| | | ° | ° | | ° | ° | | ° | ° | | | | | |
| 7.00 a. m. | 11 | 74.22 | 68.59 | 29.6179 | 73.35 | 69.34 | 29.9472 | 73.36 | 68.82 | 29.7845 | 96.89 | 0.33 | 49.10 | 0.57 |
| 9.00 a. m. | 11 | 78.79 | 70.43 | .6273 | 77.72 | 70.69 | .9563 | 77.27 | 70.28 | .7942 | 97.64 | 0.42 | 49.57 | 0.10 |
| 2.00 p. m. | 11 | 84.08 | 71.55 | .6075 | 85.60 | 72.21 | .9334 | 84.08 | 70.70 | .7730 | 97.87 | 0.65 | 49.71 | 0.04 |
| 7.00 p. m. | 11 | 78.41 | 70.39 | .5898 | 79.88 | 72.34 | .9154 | 79.02 | 70.85 | .7574 | 96.88 | 0.34 | 49.89 | 0.22 |
| 9.00 p. m. | 11 | 75.14 | 68.47 | .6077 | 76.35 | 70.97 | .9354 | 76.22 | 69.86 | .7771 | 96.81 | 0.41 | 50.11 | 0.44 |
| | | | | | | | | | | | ........ | ±0.34 | ........ | ±0.26 |
| Mean of 5 hours | | | | | | | | | | | 97.22 | ........ | 49.67 | ........ |
| Mean of the hours of 7 a. m. and 2 and 9 p. m | | | | | | | | | | | 97.19 | ±0.15 | 49.64 | ±0.11 |

### VIII.—*Height of Mount Rose barometer-station, from daily means.*

| Date. | No. of daily observations. | Mount Rose barometer-station. | | | Mount Holly barometer-station. | | | Stony Hill barometer-station. | | | Mount Rose above— | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | Mount Holly. | | Stony Hill. | |
| | | Dry bulb. | Wet bulb. | Barometer at 32°. | Dry bulb. | Wet bulb. | Barometer at 32°, +.0062. | Dry bulb. | Wet bulb. | Barometer at 32°, +.0026. | Meters. | Variation. | Meters. | Variation. |
| | | ° | ° | | ° | ° | | ° | ° | | | | | |
| July 21.. | 3 | 77.31 | 69.44 | 29.6012 | 78.42 | 72.22 | 29.9245 | 77.51 | 70.79 | 29.7676 | 95.93 | 1.29 | 49.40 | 0.25 |
| 22.. | 3 | 75.59 | 67.32 | .7259 | 75.65 | 67.02 | 30.0470 | 75.06 | 66.17 | .8878 | 94.36 | 2.86 | 47.62 | 2.03 |
| 23.. | 3 | 79.69 | 74.36 | .7168 | 80.71 | 74.01 | .0475 | 79.88 | 73.80 | .8875 | 98.29 | 1.07 | 50.78 | 1.13 |
| 25.. | 3 | 83.93 | 74.33 | .6412 | 83.34 | 75.34 | 29.9716 | 83.12 | 74.06 | .8109 | 99.05 | 1.83 | 50.93 | 1.28 |
| 26.. | 3 | 82.15 | 72.33 | .6288 | 82.63 | 72.67 | .9565 | 82.14 | 72.04 | .7957 | 97.96 | 0.74 | 49.95 | 0.30 |
| 27.. | 3 | 78.68 | 69.23 | .5809 | 81.22 | 73.16 | .9025 | 76.13 | 71.50 | .7460 | 96.05 | 1.17 | 49.26 | 0.39 |
| 28.. | 3 | 74.53 | 71.53 | .5441 | 77.98 | 73.63 | .8641 | 76.89 | 73.03 | .7069 | 94.88 | 2.34 | 48.34 | 1.31 |
| 29.. | 3 | 76.83 | 68.31 | .4584 | 76.40 | 69.96 | .7932 | 77.45 | 68.98 | .6286 | 99.52 | 2.30 | 50.72 | 1.07 |
| 30.. | 3 | 71.33 | 61.26 | .6745 | 70.52 | 62.65 | 30.0079 | 70.81 | 61.76 | .8420 | 97.14 | 0.08 | 48.89 | 0.76 |
| Aug. 1.. | 3 | 76.37 | 66.63 | .6168 | 75.76 | 66.66 | 29.9481 | 75.56 | 65.52 | .7871 | 97.76 | 0.54 | 50.32 | 0.67 |
| 2.. | 3 | 79.52 | 70.14 | .5325 | 79.39 | 74.89 | .8625 | 78.83 | 70.27 | .6999 | 98.49 | 1.27 | 49.96 | 0.31 |
| | | | | | | | | | | | ........ | ±1.15 | ........ | ±0.72 |
| | | | | | | | | | | | 97.22 | ±0.35 | 49.65 | ±0.22 |

### IX.—*Height of Newtown barometer-station, from hourly means.*

| Hour. | Number of daily observations. | Newtown barometer-station. | | | Mount Holly barometer-station. | | | Stony Hill barometer-station. | | | Newtown above— | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | Mount Holly. | | Stony Hill. | |
| | | Dry bulb. | Wet bulb. | Barometer at 32°. | Dry bulb. | Wet bulb. | Barometer at 32°, +.0046. | Dry bulb | Wet bulb. | Barometer at 32°, +.0010. | Meters. | Variation. | Meters. | Variation. |
| | | ° | ° | | ° | ° | | ° | ° | | | | | |
| 7.00 a. m. | 10 | 73.16 | 68.00 | 29.6964 | 72.86 | 68.95 | 29.9417 | 72.89 | 68.56 | 29.7789 | 72.03 | 1.12 | 24.27 | 1.37 |
| 9.00 a. m. | 10 | 77.05 | 69.58 | .7003 | 77.25 | 70.52 | .9496 | 76.78 | 70.02 | .7879 | 73.77 | 0.62 | 25.93 | 0.29 |
| 2.00 p. m. | 11 | 84.05 | 72.19 | .6834 | 85.60 | 72.21 | .9318 | 84.08 | 70.70 | .7714 | 74.57 | 1.42 | 26.46 | 0.82 |
| 7.00 p. m. | 11 | 80.07 | 70.87 | .6677 | 79.88 | 72.34 | .9138 | 79.02 | 70.85 | .7558 | 73.31 | 0.16 | 26.26 | 0.62 |
| 9.00 p. m. | 11 | 76.94 | 69.69 | .6902 | 76.35 | 70.97 | .9338 | 76.22 | 69.86 | .7755 | 72.06 | 1.09 | 25.27 | 0.37 |
| | | | | | | | | | | | ........ | ±0.74 | ........ | ±0.60 |
| Mean of 5 hours | | | | | | | | | | | 73.15 | ........ | 25.64 | ........ |
| Mean of hours of 7 a. m., 2 and 9 p. m | | | | | | | | | | | 72.89 | ±0.33 | 25.33 | ±0.27 |

X.—*Height of Newtown barometer-station, from daily means.*

| Date. | | Number of daily observations. | Newtown barometer-station. | | | Mount Holly barometer-station. | | | Stony Hill barometer-station. | | | Newtown above— | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | Mount Holly. | | Stony Hill. | |
| | | | Dry bulb. | Wet bulb. | Barometer at 32°. | Dry bulb. | Wet bulb. | Barometer at 32°, +.0046. | Dry bulb. | Wet bulb. | Barometer at 32°, +.0010. | Meters. | Variation. | Meters. | Variation. |
| | | | ° | ° | | ° | ° | | ° | ° | | | | | |
| July | 21 | 3 | 78. 19 | 70. 40 | 29. 6879 | 78. 42 | 72. 22 | 29. 9229 | 77. 51 | 70. 79 | 29. 7660 | 69. 75 | 3. 08 | 23. 20 | 2. 10 |
| | 22 | 3 | 77. 41 | 66. 62 | . 8002 | 75. 65 | 67. 02 | 30. 0454 | 75. 06 | 66. 17 | . 8862 | 72. 13 | 0. 70 | 25. 33 | 0. 03 |
| | 23 | 3 | 80. 20 | 74. 92 | . 7986 | 80. 71 | 74. 01 | 30. 0459 | 79. 88 | 73. 80 | . 8859 | 73. 50 | 0. 67 | 25. 97 | 0. 67 |
| | 26 | 3 | 82. 11 | 73. 32 | . 7114 | 82. 63 | 72. 67 | 29. 9549 | 82. 14 | 72. 04 | . 7941 | 72. 76 | 0. 07 | 24. 75 | 0. 55 |
| | 27 | 3 | 79. 61 | 71. 34 | . 6574 | 81. 22 | 73. 16 | . 9009 | 76. 13 | 71. 50 | . 7444 | 72. 61 | 0. 22 | 25. 88 | 0. 58 |
| | 28 | 3 | 76. 74 | 72. 43 | . 6218 | 77. 98 | 73. 63 | . 8625 | 76. 89 | 73. 03 | . 7053 | 71. 55 | 1. 23 | 24. 84 | 0. 46 |
| | 29 | 3 | 77. 31 | 69. 07 | . 5400 | 76. 40 | 69. 96 | . 7916 | 77. 45 | 68. 98 | . 6270 | 74. 82 | 1. 99 | 25. 94 | 0. 64 |
| | 30 | 3 | 70. 73 | 60. 60 | . 7598 | 70. 52 | 62. 65 | 30. 0063 | 70. 81 | 61. 76 | . 8404 | 71. 73 | 1. 10 | 23. 50 | 1. 80 |
| Aug. | 1 | 3 | 75. 94 | 65. 96 | . 6961 | 75. 76 | 66. 66 | 29. 9465 | 75. 56 | 65. 52 | . 7855 | 73. 81 | 0. 98 | 26. 39 | 1. 09 |
| | 2 | 3 | 78. 45 | 71. 53 | . 6072 | 79. 39 | 74. 89 | . 8609 | 78. 83 | 70. 27 | . 6983 | 75. 64 | 2. 81 | 27. 17 | 1. 87 |
| | | | | | | | | | | | | ........ | ±1. 15 | ........ | ±0. 84 |
| | | | | | | | | | | | | 72. 83 | ±0. 36 | 25. 30 | ±0. 27 |

XI.—*Difference of height between the barometer-stations of Mount Holly and Gloucester City by comparison of the hourly means.*

| Hour. | No. of daily observations. | Mount Holly. | | | Gloucester City. | | | Difference of height. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Dry bulb. | Wet bulb. | Barometer at 32°, + .0062. | Dry bulb. | Wet bulb. | Barometer at 32°. | Meters. | Mean. | Variation from mean. | Probable error. |
| | | ° | ° | | ° | ° | | | | | |
| 7.00 a. m .................. | 8 | 65. 48 | 62. 98 | 29. 9913 | 69. 36 | 65. 03 | 30. 0171 | 7. 32 | ........ | 0. 07 | |
| 9.00 a. m .................. | 8 | 72. 14 | 66. 48 | . 9903 | 72. 93 | 67. 10 | . 0160 | 7. 42 | ........ | 0. 17 | |
| 2.00 p. m .................. | 10 | 80. 61 | 69. 56 | . 9285 | 83. 27 | 70. 60 | 29. 9552 | 7. 88 | 7. 25 | 0. 63 | ±0. 43 |
| 6.00 p. m .................. | 10 | 76. 92 | 69. 42 | . 9105 | 81. 77 | 71. 53 | . 9359 | 7. 46 | ........ | 0. 21 | |
| 9.00 p. m .................. | 10 | 70. 23 | 65. 92 | . 9415 | 75. 13 | 68. 20 | . 9628 | 6. 16 | ........ | 1. 09 | |
| Mean of the hours of 7 a. m. and 2 and 9 p. m .................. | | | | | | | | | 7. 12 | | |
| Probable error of result .................. | | | | | | | | | | | ±0. 19 |

XII.—*Difference of height between the barometer-stations of Mount Holly and Gloucester City by comparison of the daily means, or mean of the 7 a. m, 2 p. m., and 9 p. m. observations.*

| Date. | No. of daily observations. | Mount Holly. | | | Gloucester City. | | | Difference of height. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Dry bulb. | Wet bulb. | Barometer at 32°, + .0062. | Dry bulb. | Wet bulb. | Barometer at 32°. | Meters. | Mean. | Variation from mean. | Probable error. |
| | | ° | ° | | ° | ° | | | | | |
| August 15.................. | 3 | 67. 14 | 61. 46 | 29. 9739 | 70. 31 | 62. 63 | 30. 0038 | 8. 59 | ........ | 1. 22 | |
| 16.................. | 3 | 68. 03 | 62. 32 | . 8832 | 73. 26 | 63. 71 | 29. 9056 | 6. 46 | ........ | 0. 91 | |
| 17.................. | 3 | 71. 96 | 66. 48 | . 8351 | 75. 40 | 68. 14 | . 8581 | 6. 69 | ........ | 0. 68 | |
| 18.................. | 3 | 74. 78 | 69. 22 | . 9350 | 78. 57 | 71. 29 | . 9613 | 7. 68 | 7. 37 | 0. 31 | ±0. 56 |
| 19.................. | 3 | 76. 30 | 69. 90 | . 9679 | 80. 01 | 71. 95 | . 9903 | 6. 55 | ........ | 0. 82 | |
| 20.................. | 3 | 77. 77 | 69. 41 | . 9478 | 79. 85 | 70. 75 | . 9767 | 8. 48 | ........ | 1. 11 | |
| 22.................. | 3 | 68. 31 | 61. 05 | 30. 1353 | 71. 98 | 63. 11 | 30. 1601 | 7. 09 | ........ | 0. 28 | |
| 23.................. | 3 | 69. 36 | 63. 01 | . 0146 | 73. 91 | 64. 80 | . 0404 | 7. 43 | ........ | 0. 06 | |
| Probable error of result .................. | | | | | | | | | | | ±0. 20 |

XIII.—*Difference of height between the barometer-stations of Gloucester City and Pine Hill by comparison of the hourly means*

| Hour. | No. of daily observations. | Gloucester City. | | | Pine Hill. | | | Difference of height. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Dry bulb. | Wet bulb. | Barometer at 32°. | Dry bulb. | Wet bulb. | Barometer at 32°, + .0026. | Meters. | Mean. | Variation from mean. | Probable error. |
| | | ° | ° | | ° | ° | | | | | |
| 7.00 a. m | 9 | 69.41 | 65.30 | 30.0084 | 66.52 | 64.07 | 29.9460 | 18.09 | ........ | 0.61 | |
| 9.00 a. m | 9 | 73.09 | 67.48 | .0091 | 73.59 | 67.52 | .9494 | 17.37 | ........ | 0.11 | |
| 2.00 p. m | 10 | 83.27 | 70.60 | 29.9552 | 81.12 | 69.33 | .8953 | 17.78 | 17.48 | 0.30 | ± 0.31 |
| 6.00 p. m | 10 | 81.77 | 71.53 | .9359 | 77.33 | 69.84 | .8774 | 17.29 | ........ | 0.19 | |
| 9.00 p. m | 10 | 75.13 | 68.20 | .9628 | 68.95 | 65.12 | .9048 | 16.88 | ........ | 0.60 | |
| Mean of the hours, 7 a. m. and 2 and 9 p. m | | | | | | | | | 17.58 | ........... | .......... |
| Probable error of result | | | | | | | | | | | ± 0.14 |

XIV.—*Difference of height between the barometer-stations of Gloucester City and Pine Hill by comparison of the daily means of the 7 a. m., 2 p. m., and 9 p. m. observations.*

| Date. | No. of daily observations. | Gloucester City. | | | Pine Hill. | | | Difference of height. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Dry bulb. | Wet bulb. | Barometer at 32°. | Dry bulb. | Wet bulb. | Barometer at 32°, + .0026. | Meters. | Mean. | Variation from mean. | Probable error. |
| | | ° | ° | | ° | ° | | | | | |
| August 15 | 3 | 70.31 | 62.63 | 30.0038 | 66.40 | 60.44 | 29.9450 | 16.95 | ........ | 0.60 | |
| 16 | 3 | 73.26 | 63.71 | 29.9056 | 67.21 | 60.70 | .8465 | 17.15 | ........ | 0.40 | |
| 17 | 3 | 75.40 | 68.14 | .8581 | 71.50 | 66.78 | .7992 | 17.25 | ........ | 0.30 | |
| 18 | 3 | 78.57 | 71.29 | .9613 | 75.63 | 69.89 | .8995 | 18.17 | ........ | 0.62 | |
| 19 | 3 | 80.01 | 71.95 | .9903 | 77.23 | 70.89 | .9304 | 17.65 | 17.55 | 0.10 | ± 0.41 |
| 20 | 3 | 79.85 | 70.75 | .9767 | 79.02 | 69.64 | .9132 | 18.73 | ........ | 1.18 | |
| 22 | 3 | 71.98 | 63.11 | 30.1601 | 65.87 | 59.35 | 30.1007 | 17.04 | ........ | 0.51 | |
| 23 | 3 | 73.91 | 64.80 | .0404 | 68.12 | 62.01 | 29.9785 | 17.92 | ........ | 0.37 | |
| 24 | 3 | 77.71 | 71.74 | 29.9101 | 74.57 | 70.01 | .8520 | 17.08 | ........ | 0.47 | |
| Probable error of result | | | | | | | | | | | ± 0.14 |

XV.—*Height of Willow Grove barometer-station, by hourly means.*

| Hour. | No. of daily observations. | Willow Grove barometer-station. | | | Mount Holly barometer-station. | | | Gloucester City barometer-station. | | | Willow Grove above— | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | Mount Holly. | | Gloucester City. | |
| | | Dry bulb. | Wet bulb. | Barometer at 32°. | Dry bulb. | Wet bulb. | Barometer at 32°, + .0046. | Dry bulb. | Wet bulb. | Barometer at 32°, — .0016. | Meters. | Variation. | Meters. | Variation. |
| | | ° | ° | | ° | ° | | ° | ° | | | | | |
| 7.00 a. m. | 8 | 65.92 | 62.70 | 29.6081 | 65.48 | 62.98 | 29.9897 | 69.36 | 65.03 | 30.0155 | 110.56 | 0.10 | 118.25 | 0.10 |
| 9.00 a. m. | 8 | 72.11 | 66.03 | .6095 | 72.14 | 66.48 | .9887 | 72.93 | 67.10 | .0144 | 111.24 | 0.58 | 118.65 | 0.50 |
| 2.00 p. m. | 10 | 80.55 | 69.38 | .5556 | 80.61 | 69.56 | .9269 | 83.27 | 70.60 | 29.9536 | 110.87 | 0.21 | 118.87 | 0.72 |
| 6.00 p. m. | 10 | 76.85 | 68.40 | .5376 | 76.92 | 69.42 | .9089 | 81.77 | 71.53 | .9343 | 110.23 | 0.43 | 118.03 | 0.12 |
| 9.00 p. m. | 10 | 70.78 | 64.78 | .5630 | 70.23 | 65.92 | .9399 | 75.13 | 68.20 | .9612 | 110.39 | 0.27 | 116.97 | 1.18 |
| Means | ...... | 73.24 | 66.26 | 29.5748 | ........ | ........ | ............ | 76.49 | 68.49 | 29.9758 | ........ | ±0.27 | ........ | ±0.50 |
| | | | | | | | | | | | 110.66 | ........ | 118.15 | ........ |
| Mean of hours, 7 a. m., 2 and 9 p. m | | | | | | | | | | | 110.61 | ±0.12 | 118.03 | ±0.22 |

XVI.—*Height of Willow Grove barometer-station, by daily means.*

| Date. | No. of daily observations. | Willow Grove barometer-station. | | | Mount Holly barometer-station. | | | Gloucester City barometer-station. | | | Willow Grove above— | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | Mount Holly. | | Gloucester City. | |
| | | Dry bulb. | Wet bulb. | Barometer at 32°. | Dry bulb. | Wet bulb. | Barometer at 32°, + .0046. | Dry bulb. | Wet bulb. | Barometer at 32°, — .0016. | Meters. | Variation. | Meters. | Variation. |
| | | ° | ° | | ° | ° | | ° | ° | | | | | |
| Aug. 13 | 3 | 75. 90 | 71. 02 | 29. 5578 | 77. 23 | 72. 97 | 29. 9293 | ........ | ........ | ............ | ........ | 0. 08 | ........ | ........ |
| 15 | 3 | 67. 78 | 59. 69 | . 5997 | 67. 14 | 61. 46 | . 9723 | 70. 31 | 62. 63 | 30. 0022 | 110. 19 | 2. 17 | 116. 74 | 1. 01 |
| 16 | 3 | 70. 43 | 62. 66 | . 5020 | 68. 03 | 62. 32 | . 8816 | 73. 26 | 63. 71 | 29. 9040 | 108. 10 | 0. 64 | 117. 64 | 0. 11 |
| 17 | 3 | 72. 28 | 65. 57 | . 4543 | 71. 96 | 66. 48 | . 8335 | 75. 40 | 68. 14 | . 8565 | 110. 91 | 1. 42 | 118. 51 | 0. 76 |
| 18 | 3 | 75. 41 | 68. 86 | . 5557 | 74. 78 | 69. 22 | . 9334 | 78. 57 | 71. 29 | . 9597 | 111. 69 | 1. 31 | 119. 41 | 1. 66 |
| 19 | 3 | 76. 72 | 71. 10 | . 5897 | 76. 30 | 69. 90 | . 9663 | 80. 01 | 71. 95 | . 9887 | 111. 58 | 1. 21 | 118. 15 | 0. 40 |
| 20 | 3 | 76. 02 | 68. 21 | . 5762 | 77. 77 | 69. 41 | . 9462 | 79. 85 | 70. 75 | . 9751 | 111. 48 | 0. 70 | 117. 98 | 0. 23 |
| 22 | 3 | 68. 01 | 59. 61 | . 7571 | 68. 31 | 61. 05 | 30. 1337 | 71. 98 | 63. 11 | 30. 1585 | 109. 57 | 1. 47 | 115. 98 | 1. 77 |
| 23 | 3 | 69. 86 | 62. 40 | . 6347 | 69. 36 | 63. 01 | . 0130 | 73. 91 | 64. 80 | . 0388 | 108. 80 | 0. 15 | 117. 75 | 0. 00 |
| 24 | 3 | 74. 14 | 69. 88 | . 5107 | ........ | ........ | ............ | 77. 71 | 71. 74 | 29. 9085 | 110. 12 | ........ | 117. 59 | 0. 16 |
| | | | | | | | | | | | ........ | ±0. 86 | ........ | ±0. 66 |
| | | | | | | | | | | | 110. 27 | ±0. 29 | 117. 75 | ±0. 22 |

XVII.—*Height of Pine Hill barometer-station, by hourly means.*

| Hour. | No. of daily observations. | Pine Hill barometer-station. | | | Mount Holly barometer-station. | | | Gloucester City barometer-station. | | | Pine Hill above— | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | Mount Holly. | | Gloucester City. | |
| | | Dry bulb. | Wet bulb. | Barometer at 32°. | Dry bulb. | Wet bulb. | Barometer at 32°, + .0036. | Dry bulb. | Wet bulb. | Barometer at 32°, — .0026. | Meters. | Variation. | Meters. | Variation. |
| | | ° | ° | | ° | ° | | ° | ° | | | | | |
| 7.00 a. m. | 8 | 66. 31 | 63. 82 | 29. 9519 | 65. 48 | 62. 98 | 29. 9867 | 69. 36 | 65. 03 | 30. 0145 | 10. 49 | 0. 15 | 18. 02 | 0. 53 |
| 9.00 a. m. | 8 | 73. 53 | 67. 20 | . 9530 | 72. 14 | 66. 48 | . 9877 | 72. 93 | 67. 10 | . 0134 | 10. 08 | 0. 26 | 17. 57 | 0. 08 |
| 2.00 p. m. | 10 | 81. 12 | 69. 33 | . 8927 | 80. 61 | 69. 56 | . 9259 | 83. 27 | 70. 60 | 29. 9526 | 10. 81 | 0. 47 | 17. 75 | 0. 26 |
| 6.00 p. m. | 10 | 77. 33 | 69. 84 | . 8748 | 76. 92 | 69. 42 | . 9079 | 81. 77 | 71. 53 | . 9333 | 9. 72 | 0. 62 | 17. 27 | 0. 22 |
| 9.00 p. m. | 10 | 68. 95 | 65. 12 | . 9022 | 70. 23 | 65. 92 | . 9329 | 75. 13 | 68. 20 | . 9602 | 10. 61 | 0. 27 | 16. 86 | 0. 63 |
| | | | | | | | | | | | ........ | ±0. 30 | ........ | ±0. 30 |
| Mean of 5 hours | | | | | | | | | | | 10. 34 | ........ | 17. 49 | ........ |
| Mean of the hours of 7 a. m. and 2 and 9 p. m. | | | | | | | | | | | 10. 64 | ±0. 13 | 17. 54 | ±0. 13 |

XVIII.—*Height of Pine Hill barometer-station, by daily means.*

| Date. | No. of daily observations. | Pine Hill barometer-station. | | | Mount Holly barometer-station. | | | Gloucester City barometer-station. | | | Pine Hill above— | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | Mount Holly. | | Gloucester City. | |
| | | Dry bulb. | Wet bulb. | Barometer at 32°. | Dry bulb. | Wet bulb. | Barometer at 32°, + .0036. | Dry bulb. | Wet bulb. | Barometer at 32°, — .0026. | Meters. | Variation. | Meters. | Variation. |
| | | ° | ° | | ° | ° | | ° | ° | | | | | |
| Aug. 13 | 3 | 79. 49 | 74. 69 | 29. 8893 | 77. 23 | 72. 97 | 29. 9283 | ........ | ........ | ............ | 11. 50 | 1. 21 | ........ | ........ |
| 15 | 3 | 66. 40 | 60. 44 | . 9424 | 67. 14 | 61. 46 | . 9713 | 70. 31 | 62. 63 | 30. 0012 | 8. 28 | 2. 01 | 16. 92 | 0. 61 |
| 16 | 3 | 67. 21 | 60. 70 | . 8439 | 68. 03 | 62. 32 | . 8805 | 73. 26 | 63. 71 | 29. 9030 | 10. 55 | 0. 26 | 17. 13 | 0. 40 |
| 17 | 3 | 71. 50 | 66. 78 | . 7966 | 71. 96 | 66. 48 | . 8325 | 75. 40 | 68. 14 | . 8555 | 10. 47 | 0. 18 | 17. 20 | 0. 33 |
| 18 | 3 | 75. 63 | 69. 89 | . 8969 | 74. 78 | 69. 22 | . 9324 | 78. 57 | 71. 29 | . 9587 | 10. 38 | 0. 09 | 18. 16 | 0. 63 |
| 19 | 3 | 77. 23 | 70. 89 | . 9278 | 76. 30 | 69. 90 | . 9653 | 80. 01 | 71. 95 | . 9877 | 11. 00 | 0. 71 | 17. 64 | 0. 11 |
| 20 | 3 | 79. 02 | 69. 64 | . 9106 | 77. 77 | 69. 41 | . 9452 | 79. 85 | 70. 75 | . 9741 | 10. 17 | 0. 12 | 18. 72 | 1. 19 |
| 22 | 3 | 65. 87 | 59. 35 | 30. 0981 | 68. 31 | 61. 05 | 30. 1327 | 71. 98 | 63. 11 | 30. 1575 | 9. 87 | 0. 42 | 17. 02 | 0. 51 |
| 23 | 3 | 68. 12 | 62. 04 | 29. 9759 | 69. 36 | 63. 01 | . 0120 | 73. 91 | 64. 80 | . 0378 | 10. 38 | 0. 09 | 17. 89 | 0. 36 |
| 24 | 3 | 74. 57 | 70. 01 | . 8494 | ........ | ........ | ............ | 77. 71 | 71. 74 | 29. 9075 | ........ | ........ | 17. 07 | 0. 46 |
| | | | | | | | | | | | ........ | ±0. 60 | ........ | ±0. 42 |
| | | | | | | | | | | | 10. 29 | ±0. 20 | 17. 53 | ±0. 14 |

XIX.—*Height of Willow Grove barometer-station, by hourly means.*

| Hour. | No. of daily observations. | Willow Grove barometer-station. | | | Pine Hill barometer-station. | | | Willow Grove barometer-station. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Dry bulb. | Wet bulb. | Barometer at 30°, —.0010. | Dry bulb. | Wet bulb. | Barometer at 32°. | Metres. | Mean. | Variation from mean. | Probable error. |
| | | ° | ° | | ° | ° | | | | | |
| 7.00 a. m | 10 | 66.64 | 63.54 | 29.6018 | 67.44 | 64.88 | 29.9443 | 99.44 | ........ | 0.73 | |
| 9.00 a. m | 10 | 72.14 | 66.69 | .6038 | 74.10 | 68.11 | .9468 | 100.72 | ........ | 0.55 | |
| 2.00 p. m | 10 | 80.55 | 69.38 | .5546 | 81.12 | 69.33 | .8927 | 100.92 | 100.17 | 0.75 | ± 0.48 |
| 6.00 p. m | 10 | 76.85 | 68.40 | .5366 | 77.33 | 69.84 | .8748 | 100.35 | ........ | 0.18 | |
| 9.00 p. m | 10 | 70.78 | 64.78 | .5620 | 68.95 | 65.12 | .9022 | 99.42 | ........ | 0.75 | |
| Mean of the hours of 7 a. m., and 2 and 9 p. m. | | | | | | | | | 99.93 | ............ | ........ |
| Probable error of mean | | | | | | | | | ........ | ............ | ± 0.21 |

XX.—*Height of Willow Grove barometer-station, by daily means.*

| Date. | No. of daily observations. | Willow Grove Barometer-station. | | | Pine Hill Barometer-station. | | | Willow Grove. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Dry bulb. | Wet bulb. | Barometer at 32°, —.0010. | Dry bulb. | Wet bulb. | Barometer at 32°. | Meters. | Mean. | Variation from mean. | Probable error. |
| | | ° | ° | | ° | ° | | | | | |
| August 13 | 3 | 75.90 | 71.02 | 29.5568 | 79.49 | 74.69 | 29.8893 | 98.89 | ....... | 1.02 | |
| 15 | 3 | 67.78 | 59.69 | .5987 | 66.40 | 60.44 | .9434 | 99.62 | ....... | 0.29 | |
| 16 | 3 | 70.43 | 62.66 | .5010 | 67.21 | 60.70 | .8439 | 100.12 | ....... | 0.21 | |
| 17 | 3 | 72.28 | 65.57 | .4533 | 71.50 | 66.78 | .7966 | 101.48 | ....... | 1.57 | |
| 18 | 3 | 75.41 | 68.86 | .5547 | 75.63 | 69.89 | .8969 | 100.97 | 99.91 | 1.06 | ± 0.64 |
| 19 | 3 | 76.72 | 71.10 | .5887 | 77.23 | 70.89 | .9278 | 100.51 | ....... | 0.60 | |
| 20 | 3 | 76.02 | 68.21 | .5752 | 79.02 | 69.64 | .9106 | 99.46 | ....... | 0.45 | |
| 22 | 3 | 68.01 | 59.61 | .7561 | 65.87 | 59.35 | 30.0981 | 98.56 | ....... | 1.35 | |
| 23 | 3 | 69.86 | 62.40 | .6337 | 68.12 | 62.04 | 29.9759 | 99.04 | ....... | 0.87 | |
| 24 | 3 | 74.14 | 69.88 | .5097 | 74.57 | 70.01 | .8494 | 100.47 | ....... | 0.56 | |
| Probable error of result | | | | | | | | | | | ± 0.20 |

XXI.—*Heights of Yard, Bethel, and Lippincott barometer-stations, by hourly means.*

| Hour. | Yard barometer-station. | | | | Bethel barometer-station. | | | | Lippincott barometer-station. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. of observations. | Above Gloucester barometer-station. | | Variation. | No. of observations. | Above Gloucester barometer-station. | | Variation. | No. of observations. | Above Gloucester barometer-station. | | Variation. |
| | | Meters. | Feet. | | | Meters. | Feet. | | | Meters. | Feet. | |
| | | | | *m.* | | | | *m.* | | | | *m.* |
| 7.00 a. m | 11 | 97.38 | 319.48 | 0.27 | 11 | 101.46 | 332.87 | 0.36 | 10 | 24.96 | 81.89 | 0.21 |
| 9.00 a. m | 11 | 98.31 | 322.54 | 0.66 | 10 | 101.93 | 334.43 | 0.11 | 11 | 24.77 | 81.28 | 0.02 |
| 2.00 p. m | 10 | 97.61 | 320.25 | 0.04 | 11 | 102.56 | 336.47 | 0.74 | 11 | 24.71 | 81.08 | 0.04 |
| 6.00 p. m | 11 | 98.17 | 322.08 | 0.52 | 11 | 102.02 | 334.70 | 0.20 | 11 | 24.99 | 82.00 | 0.24 |
| 9.00 p. m | 11 | 96.80 | 317.61 | 0.85 | 11 | 101.12 | 331.77 | 0.70 | 11 | 24.34 | 79.85 | 0.41 |
| **Probable error of one result** | ...... | ............ | ............ | ±0.41 | ...... | ............ | ............ | ±0.37 | ...... | ............ | ............ | ±0.18 |
| **Mean** | ...... | 97.65 | ............ | | ...... | 101.82 | ............ | | ...... | 24.75 | ............ | ........ |
| **Mean of the hours 7 a. m., 2 and 9 p. m.** | ...... | 97.26 | ............ | ±0.18 | ...... | 101.71 | ............ | ±0.17 | ...... | 24.67 | ............ | ±0.08 |

XXII.—*Heights of Yard, Bethel, and Lippincott barometer-stations, by daily means.*

| Date. | Yard barometer-station. | | | | Bethel barometer-station. | | | | Lippincott barometer-station. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. of observations. | Above Gloucester barometer-station. | | Variation. | No. of observations. | Above Gloucester barometer-station. | | Variation. | No. of observations. | Above Gloucester barometer-station. | | Variation. |
| | | Meters. | Feet. | | | Meters. | Feet. | | | Meters. | Feet. | |
| | | | | m. | | | | m. | | | | m. |
| August 27 | 3 | 95.73 | 314.07 | 1.58 | 3 | 102.19 | 335.27 | 0.46 | ...... | ........ | ........ | ........ |
| 29 | 3 | 99.10 | 325.12 | 1.79 | 3 | 102.14 | 335.12 | 0.41 | 3 | 23.90 | 78.43 | 0.71 |
| 30 | 3 | 97.24 | 319.04 | 0.07 | 3 | 101.37 | 332.57 | 0.36 | 3 | 23.67 | 77.65 | 0.94 |
| 31 | 3 | 97.29 | 319.19 | 0.02 | 3 | 101.66 | 333.54 | 0.08 | 3 | 24.63 | 80.79 | 0.02 |
| Septemb'r 1 | 3 | 99.03 | 324.91 | 1.72 | 3 | 102.68 | 336.88 | 0.95 | 3 | 24.97 | 81.94 | 0.36 |
| 2 | 3 | 97.70 | 320.55 | 0.39 | 3 | 103.58 | 339.83 | 1.85 | 3 | 25.93 | 85.06 | 1.32 |
| 3 | 3 | 96.76 | 317.46 | 0.55 | 3 | 102.10 | 334.97 | 0.37 | 3 | 23.96 | 78.62 | 0.65 |
| 5 | 3 | 95.61 | 313.68 | 1.70 | 3 | 100.26 | 328.95 | 1.47 | 3 | 23.53 | 77.19 | 1.08 |
| 6 | 3 | 97.42 | 319.61 | 0.11 | 3 | 100.43 | 329.50 | 1.30 | 3 | 24.46 | 80.25 | 0.15 |
| 7 | ...... | ........ | ........ | ........ | 3 | 101.06 | 331.55 | 0.67 | 3 | 25.34 | 83.12 | 0.73 |
| 8 | 3 | 97.21 | 318.95 | 0.10 | 3 | 101.55 | 333.24 | 0.18 | 3 | 25.76 | 84.52 | 1.15 |
| | ...... | ........ | ........ | ±0.78 | ...... | ........ | ........ | ±0.65 | ...... | ........ | ........ | ±0.58 |
| | ...... | 97.31 | ........ | ±0.25 | ...... | 101.73 | ........ | ±0.20 | ...... | 24.61 | ........ | ±0.18 |

THE RESULTS—THEIR CHARACTER AND VALUE.

The following table contains a synopsis of the results. It also shows the wandering from the mean in each case, the probable error of one day's observations, and the mean of all.

XXIII.—*Results obtained from the three daily observations at the hours of 7 a. m. and at 2 and 9 p. m, representing the daily mean of the twenty-four hours.*

| Stations. | Distance apart in miles. | Number of daily means. | Difference in height by barometer. | Maximum variation from mean. | Minimum variation from mean. | Mean variation from mean. | Probable error. | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | One daily mean. | Final result. |
| GROUP A. | | | | | | | ± | ± |
| | | | m. | m. | m. | m. | m. | m. |
| Stony Hill from Mount Holly | 13.75 | 11 | 47.43 | 1.35 | 0.05 | 0.72 | 0.57 | 0.17 |
| Mount Rose from Stony Hill | 18.50 | 11 | 49.65 | 2.03 | 0.25 | 0.86 | 0.72 | 0.22 |
| Mount Rose from Mount Holly | 25.25 | 11 | 97.22 | 2.86 | 0.08 | 1.41 | 1.15 | 0.35 |
| Newtown from Stony Hill | 20.00 | 10 | 25.30 | 2.10 | 0.03 | 0.89 | 0.84 | 0.27 |
| Newtown from Mount Holly | 18.50 | 10 | 72.83 | 3.08 | 0.07 | 1.17 | 1.15 | 0.36 |
| GROUP B. | | | | | | | | |
| Gloucester from Mount Holly | 19.75 | 8 | 7.37 | 1.22 | 0.06 | 0.67 | 0.56 | 0.20 |
| *Pine Hill from Gloucester* | 9.33 | 9 | 17.55 | 1.18 | 0.10 | 0.51 | 0.41 | 0.14 |
| Pine Hill from Mount Holly | 18.00 | 9 | 10.29 | 2.01 | 0.09 | 0.57 | 0.60 | 0.20 |
| Willow Grove from Mount Holly | 19.25 | 9 | 110.27 | 2.17 | 0.08 | 1.02 | 0.86 | 0.29 |
| Willow Grove from Gloucester | 17.50 | 9 | 117.75 | 1.77 | 0.00 | 0.68 | 0.66 | 0.22 |
| Willow Grove from Pine Hill | 21.60 | 10 | 99.91 | 1.57 | 0.21 | 0.80 | 0.64 | 0.20 |
| GROUP C. | | | | | | | | |
| Yard from Gloucester | 15.00 | 10 | 97.31 | 1.79 | 0.02 | 0.80 | 0.78 | 0.25 |
| Bethel from Gloucester | 19.33 | 11 | 101.73 | 1.85 | 0.08 | 0.74 | 0.65 | 0.20 |
| Lippincott from Gloucester | 15.00 | 10 | 24.61 | 1.36 | 0.02 | 0.71 | 0.58 | 0.18 |

**1. In group A we have two known points to determine a third and fourth; in group B we have three known points to determine a fourth; in group C we have one known point to determine a second, third, and fourth.**

2. The observations were made during the months of July, August, and September, and each difference of height was determined by about ten daily means, or thirty observations in ten days.

3. The probable error of the final result in the fourteen different sets ranges from $\pm$ 0$^{m}$.14 for the shortest line to $\pm$ 0$^{m}$.35 for the longest line, the mean being $\pm$ 0$^{m}$.23.

The final discussions of the barometric observations and the comparison of their results with those determined by means of the spirit-level will be presented as soon as the results by the latter operation are checked.

# APPENDIX No. 9.

*Heights above the half-tide level of the Ocean of trigonometrical stations determined by the United States Coast Survey.*

Level of reference—the ground, unless otherwise stated.

The letter L denotes that the height was determined by leveling.

| Name of station. | Latitude. | Longitude. | Height in feet. |
|---|---|---|---|
| | ° ′ | ° ′ | |
| East Base, Epping Plains, Maine | 44 40.1 | 67 49.9 | 254.7 L |
| West Base, Epping Plains, Maine | 44 41.5 | 67 56.2 | 239.2 L |
| Pigeon, Maine | 44 27.3 | 67 53.4 | 314.7 L |
| Howard, Maine | 44 37.8 | 67 23.7 | 269.1 L |
| Thomas Hill, Bangor, Maine | 44 48.4 | 68 47.0 | 242.0 L |
| Prince Regent's Redoubt ground, Maine | 44 55.2 | 67 00.6 | 196.8 L |
| Bramhall, Portland, Maine | 43 38.8 | 70 16.6 | 175.5 L |
| Tashua, Connecticut | 41 15.6 | 73 15.0 | 608.1 L |
| North End, Massachusetts Base, base of tower | 42 03.1 | 71 12.4 | 230.9 L |
| South End, Massachusetts Base, railroad track | 41 54.8 | 71 18.3 | 108.0 L |
| Nantucket Cliff, (1867,) Massachusetts | 41 17.6 | 70 06.9 | 57.6 L |
| Mount Washington, (Eastern Peak,) New Hampshire | 44 16.2 | 71 18.2 | 6,293 |
| Sebattis Mountain, Maine | 44 08.6 | 70 04.7 | 799.7 L |
| Coddon's Hill, Massachusetts | 42 31.0 | 70 51.3 | 117.8 L |
| Dorchester Heights, surface of parapet of old fortification, Massachusetts | 42 20.0 | 71 02.6 | 139.8 L |
| Nantasket, surface of parapet of old fortification, Massachusetts | 42 18.2 | 70 54.3 | *127.8 L |
| Portland, bench-mark, railroad wharf | | | 8.6 L |
| The following heights are those above the Potomac at the Navy-Yard: | | | |
| United States Capitol, eastern front, ground | 38 53.3 | 77 00.6 | 88.7 |
| Coast Survey Office, floor of vestibule | 38 53.2 | 77 00.6 | 78.0 L |
| United States Naval Observatory, top of dome | 38 53.7 | 77 03.1 | 149.5 |
| Kengley's House, Georgetown Heights, ground | 38 55.5 | 77 04.5 | 382.6 |
| Military Asylum, south side tower, ground | 38 56.4 | 77 00.7 | 328 |
| Lunatic Asylum, north front tower, ground | 38 51.2 | 77 00.0 | 172 |
| Smithsonian Institute, north side main entrance, ground | 38 53.3 | 77 01.6 | 32 |
| North end Kent Island base | 38 58.4 | 76 20.5 | 17.7 L |
| North end Bodies Island base | 35 53.9 | 75 35.9 | 6.1 L |
| South end Bodies Island base | 35 48.5 | 75 33.0 | 5.2 L |
| Point San José | 37 48.3 | 122 25.6 | 117.5 L |
| Fort Point | 37 48.3 | 122 28.6 | 186 |
| Presidio Hill, San Francisco | 37 47.5 | 122 27.8 | 384 |
| Lime Point Bluff | 37 49.5 | 122 28.9 | 495 |
| Point Diablo | 37 49.1 | 122 30.0 | 202 |
| Point Boneta | 37 49.1 | 122 31.8 | 283 |
| Point Lobos, 1 | 37 47.1 | 122 30.1 | 326 |
| Topsail Rock, summit | | | 81 |
| Summit back of Point Diablo | | | 912 |
| Telegraph Hill | 37 48.0 | 122 24.3 | 300 |
| Alcatraz Island | 37 49.5 | 122 25.3 | 142 |
| Saucelito Point | 37 51.2 | 122 28.8 | 94.2 L |
| Point de los Cavallos | 37 50.0 | 122 28.3 | 126 |
| Angel Island northwest | 37 51.5 | 122 26.7 | 159 |
| Peninsula Hill | 37 52.1 | 122 27.9 | 367 |
| Strawberry Hill | 37 52.6 | 122 29.9 | 188 |
| Yerba Buena | 37 48.5 | 122 21.9 | 345 |
| Point Avisadera | 37 43.4 | 122 21.8 | 170.9 L |
| Guano Island | 37 34.2 | 122 15.7 | 28.4 L |
| Angel Island Peak | 37 51.6 | 122 25.8 | 782 |
| Rocky Island | 37 53.7 | 122 21.3 | 157 |
| Molate Point | 37 56.7 | 122 25.2 | 133 |
| Point San Pablo | 37 57.8 | 122 25.6 | 97 |
| Point San Quentin | 37 56.5 | 122 28.9 | 127 |
| Contra Costa, 3 | 37 52.9 | 122 18.8 | 96 |

APPENDIX No. 9—Continued.

| Name of station. | Latitude. | Longitude. | Height in feet. |
|---|---|---|---|
| | ° ′ | ° ′ | |
| Molate Island | 37 55.6 | 122 25.8 | 169 |
| Richmond Point | 37 54.6 | 122 23.0 | 192 |
| Marin Island | 37 57.7 | 122 28.0 | 74 |
| San Rafael Creek | 37 58.1 | 122 29.2 | 112 |
| Bluff Point | 37 53.2 | 122 26.7 | 177 |
| California City Point | 37 54.7 | 122 28.5 | 75 |
| High Hill | 37 56.4 | 122 24.1 | 490 |
| Point San Pedro | 37 59.1 | 122 27.1 | 356 |
| Point Penole | 38 00.6 | 122 22.0 | 68 |
| Petaluma Creek | 38 06.1 | 122 29.4 | 111 |
| Mare Island, southeast | 38 04.5 | 122 15.3 | 283 |
| Mare Island, northwest | 38 05.2 | 122 16.0 | 101 |
| Vallejo, 1 | 38 05.2 | 122 14.7 | 87 |
| Vallejo, 3 | 38 04.1 | 122 13.4 | 371 |
| Abbott | 38 03.1 | 122 14.6 | 375 |
| Bush Hill | 38 02.9 | 122 12.3 | 481 |
| Straits, northwest base | 38 05.1 | 122 15.4 | 9.2 L |
| East End, Pulgas base | 37 28.4 | 122 08.1 | 19.3 L |
| West End, Pulgas base | 37 28.7 | 122 15.3 | 129.4 L |
| Santa Cruz, station | 36 58.5 | 122 03.3 | 359.2 L |
| Santa Cruz, point | 36 56.9 | 122 01.6 | 31.8 L |
| San Diego, west base | 32 41.7 | 117 13.6 | 12.9 L |
| Fitch's Hill | 32 42.9 | 117 14.6 | 279 |
| Astronomical Observatory, 1851-'2, San Diego | 32 42.0 | 117 14.7 | 202 |
| Point Loma | 30 40.2 | 117 14.6 | 420 L |
| Old Town, San Diego | 32 45.0 | 117 11.3 | 305 |
| Point Conception, astronomical station | 34 26.9 | 120 26.7 | 112 L |
| Ross Mountain | 38 30.2 | 123 07.2 | 2205.5 L |
| Red Hill | 37 32.9 | 122 05.7 | 187.5 L |
| Bodega Head | 38 18.3 | 123 03.8 | 241.1 L |
| Sonoma Mountain | 38 19.3 | 122 34.5 | 2291.9 L |
| Tomales Bay | 38 10.8 | 122 56.8 | 673.0 L |
| Smith Signal | 38 14.7 | 122 56.2 | 568 |
| Dominguez | 33 51.8 | 118 14.2 | 192 L |
| Santa Barbara | 34 24.2 | 119 42.8 | 459 L |
| West Beach | 33 52.5 | 118 23.7 | 241 L |
| Trident, ground | 48 47.1 | 122 56.4 | 18.5 L |
| Matia Island, east | 48 44.6 | 122 49.1 | 58.0 L |

# APPENDIX No. 10.

## DESCRIPTIONS OF BENCH-MARKS AT TIDAL STATIONS.

*Eastport, Maine.*—The bench-mark is the upper side of a copper bolt in a ledge in front of and near the dwelling house of J. S. Pearce, and also near his wharf. This bench-mark is 25.5 feet above mean low water, and 7.4 feet above mean high water.

*Jonesport.—Moose-a-bec Reach, Maine.*—The bench-mark is a cross cut on a ledge a little west of the land termination of the steamboat wharf at Jonesport. The ledge has a crevice in it. The horizontal line of the cross is 4.34 feet above mean low water, and 7.38 feet below mean high water.

*Addison Point, Maine.*—The bench mark is on the pier on the south side of the bridge over Pleasant River. It is 12.82 feet above mean low water, and 1.52 feet above mean high water. It is 7.17 feet above the mean level of the water. The granite monument at the east base on Epping Plains is 254.72 feet above the mean level of the water at this point. Another bench-mark was made at the bottom of the northwest corner of Captain L. P. Dy—'s store. This bench-mark is 3.29 feet above the other. Latitude of Addison Point Bridge, 44° 37′ 05″.5; longitude, $4^h$ $31^m$ $30^s$.

*Prospect Harbor, Maine.*—The bench-mark is cut in a rock near the southeast corner of Captain Handy's wharf, which is on the west side of Prospect Harbor, bearing about west from the light-house. The bench-mark is 2 feet from the south side of the wharf, 7.0 feet above mean low water, and 3.8 feet below mean high water.

*Bass Harbor.—Mount Desert Island, Maine.*—The bench-mark was cut with a chisel in a ledge a little way northeast from the northeast corner of Holden's store, at the entrance to Holden's wharf on the west side of Bass Harbor. The cut is about 3 inches long, ½ inch wide, and ¼ inch deep, horizontal and just above high-water mark. Another mark was made by driving three small nails in a horizontal line at a suitable place in the north face of Holden's wharf. The middle nail is the bench-mark, and is at the same height as the mark in the ledge. They are 11.15 feet above mean low water, and 1.05 feet above mean high water.

*Carver's Harbor, Fox Islands, Maine.*—The bench-mark is a copper bolt inserted into a drill hole on a ledge about 93 feet north-northeast of the coal shed on the steamboat wharf of Kittridge & Webster, and is covered by very high tides. The top of the copper bolt is 6.79 feet above mean low water, and 0.48 feet above mean high water.

*North Haven, Fox Islands, Maine.*—The tide-house is on a pier connected with Beverage's wharf, which is the first wharf on the left-hand side after entering the harbor. The primary bench-mark is the center of a cross cut on top of a rock near high-water mark on the opposite side of the creek, bearing northeast by east half east, 540 feet from the tide-house, and is approximately 12.90 feet above mean low water, and 2.92 feet above mean high water. The second bench-mark is the center of a cross cut in the top of a rock 350 feet north from the tide-house, and is 15,735 feet higher than the other.

*Rockland, Maine.*—The bench-mark is a copper bolt in a rocky ledge, near the entrance to commercial wharf on the north side. It is 12.67 feet above mean low water, and 3.07 feet above mean high water.

*Camden, Maine.*—The bench-mark consists of a round hole, ¾ inch diameter and ¾ inch deep, drilled in the upper edge of a small upheaved lime-rock, which is nearly half way between high and low water marks. It is situated 38 feet 10 inches eastward from the east corner of the stone pier of the lower steamboat wharf. It is 5.05 feet above mean low water, and 4.75 feet below mean high water.

*Belfast, Maine.*—The bench-mark is a cross cut in the rock foundation under T. Simpson's wharf, at the shore end. It is 7.5 feet above mean low water, and 2.2 feet below mean high water.

*Bangor, Maine.*—The bench-mark is on the south side of the lower steamboat wharf, close to and in front of Mr. Boynton's carpenter-shop. It is a cross cut in the top of the sill of the wharf, 15.36 feet above mean low water, and 3.16 feet above mean high water.

*Pleasant Point, Topsham, Maine, on the Androscoggin River.*—The bench-mark is on the north side of a small rocky island belonging to Mr. Douglass, near Pleasant Point, Topsham. It is a hole drilled in the rock inside of a triangle. It can be readily found, as it and the letters B. M. are painted black. It is 8.29 feet above mean low water, and 3.63 feet above mean high water.

*Harpswell, Maine.*—The permanent bench-marks at this place are two holes drilled in the rock just at the place where the Harpswell steamboat-wharf joins the rock, and on the north side of the wharf. Leaden plugs are well inserted in them. The hole A is 9.47 feet above mean low water, and 0.54 foot above mean high water. The hole B is 1.259 feet directly above A.

*Portland, Maine.*—The bench-mark is the intersection of a cross cut in the head of a copper bolt, which is driven into the granite sill of the Atlantic and Saint Lawrence depot, 6 inches from the ground, and 12 inches from the extreme southwest corner of the brick part of the building, and surrounded by a circle cut in the granite. It is approximately 19.96 feet above mean low water, and 10.86 feet above mean high water.

*Portsmouth, New Hampshire.*—The bench-mark is a cross cut in a copper bolt driven into the solid rock near the entrance to the wharf a little way from the sally-port at the northwest corner of Fort Constitution, and near the corner. It is 14.60 feet above mean low water, and 6 feet above mean high water.

*Rockport, Massachusetts.*—The bench-mark is a circle cut in the southern wall of the northern pier of the breakwater, at the entrance of the western harbor. It is 37 feet from the end of the pier, and 4 feet 8 inches from the top. The center of the circle is 8.9 feet above mean low water, and 0.3 foot above mean high water. Near it are cut in the stones, U. S. C. S., 1857.

*Boston navy-yard, Massachusetts.*—The top of the wall or quay at the entrance of the dry-dock in the Charlestown navy-yard is 14.69 feet above mean low water, and 4.89 feet above mean high water. Another bench-mark is at the top of the facing of the dry-dock on the west side, near its head, directly over the foot of the long steps, being the point of an arrow cut in the side of the stone. This is 0.176 feet lower than the other.

*Boston lower light, Massachusetts.*—The bench-mark is a circle cut in the face of a stone, with the letters C. S. rudely cut near it. This rock forms a part of a ledge running east and west. The bench-mark is in the range between the light-house and Long Island Hotel, distant from the light-house about 340 feet. The center of the circle is 25.63 feet above mean low water, and 16.33 feet above mean high water.

*Plymouth, Massachusetts.*—The bench-mark is on Plymouth pier, the lower edge of a white mark on the west side of the pier, marked Tide-level G, being 14.61 feet above mean low water, and 4.43 feet above mean high water.

*Monomoy Point, Massachusetts.*—The bench-mark is a cross in the head of the middle one of three copper bolts, near the northwest corner of Powder Hole wharf, in the east face of a horizontal timber 12 inches square. It is 6.6 feet above mean low water, and 2.7 feet above mean high water. Another bench-mark is a row of copper nails in the west face of a pile, near the northeast jog of Powder Hole wharf. It is 2.58 feet lower than the other.

*Nantucket, Massachusetts.*—The bench-mark is a cross cut in the head of a half-inch copper bolt on the south side of Commercial wharf, in the face of a flat stone. It is 4.85 feet above mean low water, and 1.75 feet above mean high water.

*Vineyard Haven, or Holmes' Hole, Massachusetts.*—The bench-mark is just outside of Holmes' Hole, on West Chop, and about a quarter of a mile northwest of the light-house. It is the highest point of a double-headed rock, about 18 inches out of the ground, and just to the east of the bluff where the old light-house stood. There are several rocks to the west of it, but no one of any size to the east until you reach one about 120 feet east of it that is just out of water at low water. The bench-mark is 4.26 feet above mean low water, and 2.56 feet above mean high water.

*Round Hill, or Dumpling Rock light-house, near the entrance to New Bedford Harbor, Massachusetts.*—At the northeast corner of the wall surrounding the light-house one of the stones is chiseled out to the depth of one-fourth of an inch and the lower horizontal edge dressed smooth. This edge is 14.75 feet above mean low water, and 10.95 feet above mean high water.

*Conanicut Island, East Ferry, Rhode Island.*—The bench-mark is the highest point of a bowlder about 5 feet out of the ground, 2.55 feet above mean low water, and 1.35 below mean high water.

Its major axis is about 6 feet east and west. This bench-mark lies 126 meters southward of southeast corner of South Ferry wharf, and 44 meters off high-water line. The datum plane is a flat space cut on the top, and surrounded by an elliptic cut of about 3 by 2 inches, a little distance from which the letters C. S. are rudely but distinctly cut.

*Position of bench-mark.*

| | | |
|---|---|---|
| From rock: | | |
| Fort Adams staff and Goat Island light | 30° | 58 |
| Goat Island light and southeast corner south wharf | 79 | 20 |
| From southeast corner South Ferry wharf: | | |
| Bench and Fort Adams staff | 67 | 30 |
| Bench and Newport shot-tower | 82 | 12 |
| Fort Adams staff and Goat Island light | 31 | 01 |
| Goat Island light and "Hop. Sig." | 75 | 08 |

*East Greenwich, Rhode Island.*—The bench-mark is a copper bolt driven into a large rock, forming a part of Hill's wharf, and on the south side of it. It is 3.98 feet below the top of the wharf, 3.06 feet above mean low water, and 1.44 below mean high water.

*Bristol, Rhode Island.*—The bench-mark is a copper bolt driven into a hole drilled in a large rock in front of Captain West's barn. This rock stands alone, between the barn and house and the wharves. The rock is 88½ feet from the garden gate, 91 feet from the corner of a stone wall, 78 feet from the corner of the shed nearest the house, and 51 feet from high-water mark. The bench-mark is 10.8 feet above mean low water, and 6.1 feet above mean high water.

*Warren, Rhode Island.*—The bench-mark is on the north side of Carr & Ingraham's wharf. It is a copper bolt driven into a stone in the wharf 30 feet 5¼ inches from its west end, and 3 feet 2 inches below its top; and it has three circles painted around it, black, white, and black. It is 4.12 feet above mean low water, and 0.37 foot below mean high water.

*Nayatt Point, Rhode Island.*—The bench-mark is a copper bolt driven into the north side of a large bowlder about 120 meters from the steamboat wharf, in the direction of Nayatt light. The bolt has a large white circle painted around it, and is 3.94 feet above mean low water, and 0.80 foot below mean high water.

*Providence, Rhode Island.*—The bench-mark is about 28 feet northward from the center of Vue de l'Eau wharf, where it joins the shore, on the east side of Providence River, about two and a half miles below the city of Providence. It is a copper bolt driven into the solid rock near the inner end of the wharf, on the shore facing the westward. The bolt is surrounded by a circle of black and white paint, and is 18 inches from the top of the rock; and it is 4.65 feet above mean low water, and 0.46 foot below mean high water.

*New London, Connecticut.*—The locality is Captain S. A. Chapman's wharf, about two and a half miles above New London, on the east side of the Thames River, the proposed site for a navy-yard for the manufacture of iron-clad vessels and other heavy iron-work for the United States Navy. The bench-mark is a hole drilled in a rock on shore, near the wharf, and filled with sulphur It is 9.22 feet above mean low water, and 6.62 feet above mean high water.

*New Haven, Connecticut.*—The bench-mark was made near the chemical works at East Haven on the inner face of the breakwater, in line with the western face of the wharf opposite. It consists of a cut in the string-piece of the breakwater, with a large spike driven above it and another below it. The cut is 6.6 feet above mean low water, and 0.7 foot above mean high water.

*Montauk Point, New York.*—The bench-mark is nearly 1,000 paces northwest by west from the light-house, and consists of two holes drilled about an inch deep into the largest and most conspicuous rock lying at high-water mark. One of the holes has a circle cut around it 4 inches in diameter with the letters U. S. outside. This bench-mark is 9.49 feet above mean low water, and 7.77 feet above mean high water.

*Governor's Island, New York.*—Our principal bench-mark for New York harbor is on Governor's Island, near our tide-gauge there. It is the lower edge of a straight line cut in a stone wall, at the head of a wooden wharf, and it is 14.59 feet above mean low water, and 10.19 feet above mean high water. The letters U. S. C. S. are cut in the same stone. The present mark covers an older one of the same height.

*Brooklyn, New York.*—The bench-mark consists of a cross with the letters U. S. cut in the southeast corner of the door of the store-house belonging to the Atlantic Dock Company, which is the only door opening upon the ferry wharf. The center of the cross is 0.48 foot above the offset at the northeast end of the buildings. This bench-mark is 2.85 feet below the one opposite on Governor's Island. Hence it is 11.74 feet above mean low water, and 7.34 feet above mean high water.

*Brooklyn navy-yard, New York.*—The bench-mark is on the corner of the wharf at Admiral's Landing, where a row of copper tacks in the pile is the bench-mark, and the top of the pile is 3.60 feet above it. It is 7.22 feet above mean low water, and 2.87 feet above mean high water.

*Rondout, Hudson River, New York.*—The bench-mark is a cut in the granite step of the light-house, over which is marked B. M. It is 7.4 feet above mean low water, and 3.6 feet above mean high water. Another cut is made in the granite step of the light-house, the fourth step from the top, and marked B. M. This is 2½ inches above the other bench-mark.

*West Point, New York, on the Hudson River.*—The bench-mark is on the west side of the north-west corner of the north wing of the equipment shed, where a hole was drilled into the granite door-post and filled with a copper bolt driven into it. The center of the copper bolt is 13.66 feet above mean low water, and 10.95 feet above mean high water.

*Sandy Hook, New Jersey.*—The bench-mark is on the principal light-house, which is an octagonal tower resting on a circular base of unhewn stones and of larger size. It is a horizontal cut between two stones, 4 inches to the westward of the northwest angle of the tower, 9½ inches above the ledge, and 2 feet 8½ inches above the ground. The width of the side of the octagon at the bench-mark is 11 feet 10½ inches, and 5 feet 5¾ inches above the bench-mark is another ledge where the periphery of the tower is again reduced. The lower edge of the horizontal cut is the bench-mark, below which a curve has been cut in the stone to make the place more conspicuous. The bench-mark is 21.7 feet above mean low water, and 17.0 feet above mean high water.

*Keyport, New Jersey.*—The bench-mark is a circle about 6 inches diameter cut into the top of a stone in front of Lewis Morris's house at Keyport. It is 18.53 feet above mean low water, and 12.91 feet above mean high water, and it is 15.72 feet above mean tide.

*Gloucester, New Jersey, about three miles below Philadelphia.*—The bench-mark is the center of a triangle cut in a large block of granite which lies in a granite wall against the river. It is on the river side of the wall, about 56 yards southward from the mark on the northwest corner of the Buena Vista house. It is 7.89 feet above mean low water, and 1.62 feet above mean high water.

*Baltimore, Maryland.*—The bench-mark is an iron spindle in the center of Fort Carroll, below the city. The top of this spindle is 4.95 feet above mean low water, and 4.05 feet above mean high water.

*Annapolis, Maryland.*—The bench-mark is a cross cut in the head of a copper bolt inserted in the bricks of a chimney which projects from the end of a frame house. It is about 3½ feet from the ground, and 95 feet distant north 48° west from the place of observation on the eastern side of Taylor's wharf. It is 7.94 feet above mean low water, and 7.85 feet above mean high water.

*Old Point Comfort, Virginia.—Fortress Monroe.*—A line cut in the wall of the light-house, one foot from the ground, on the southwest side, is 11.0 feet above mean low water, and 8.5 feet above mean high water. A new bench-mark was cut in the wall of Fortress Monroe a little to the right of the southwest postern gate as you enter. It is a cross about 6 inches in diameter, and about half an inch deep, cut in a granite block, and painted black. The bench-mark is the intersection of the two arms of the cross. It is 0.033 feet above the old bench-mark on the light-house.

*Washington navy-yard, D. C.*—The bench-mark is on the platform at the flagstaff. The surface of the inner circle of stone is 40.51 feet above mean low water, and 37.61 feet above mean high water.

*Smithville, North Carolina.*—The bench-mark is the top of a granite post set in the ground at the head of the Barracks' wharf. It is 9.17 feet above mean low water, and 4.77 feet above mean high water.

*Point Peter, North Carolina, opposite Wilmington.*—The bench-mark is a granite post buried nearly flush with the ground, and south of a small outbuilding 3½ feet, and in range with the west side of the same. It is 90 or 100 feet from the east side of Point Peter saw-mill wharf. The top of this post is 3.72 feet above mean low water, and 1.02 feet above mean high water. A post on the south side of the wharf, 17 feet from the southeast corner, is marked at top with 4 copper nails, which are 1.11 feet higher than the other bench-mark.

*Beaufort, North Carolina.*—The bench-mark is on the upper edge of the wharf at Fort Macon, and designated by five copper nails, one of which is placed at the center, and the others at equal intervals around it. It is 7.03 feet above mean low water, and 4.23 feet above mean high water.

*Charleston, South Carolina.*—The outer and lower edge of the embrasure of gun No. 3, at Castle Pinckney, is 10.13 feet above mean low water, and 5.03 feet above mean high water. There is another bench-mark on the steps of the new custom-house, 4½ inches above the lower steps on the northeast side. It is 12.3 feet above mean low water, and 7.2 feet above mean high water.

*Fort Pulaski, Georgia, mouth of Savannah River.*—The bench-mark is indicated by five copper nails on the coping of the wharf on the east-northeast side of Cockspur Island. The wharf is firm and durable, mostly resting on a granite foundation. The bench-mark is 9.24 feet above mean low water, and 2.34 feet above mean high water.

*Savannah, Georgia.*—The bench-mark is indicated by five copper nails on the coping at the southeast side of the dry-dock wharf. It is 8.66 feet above mean low water, and 2.16 feet above mean high water.

*Old Fernandina, Florida.*—The bench-mark consists of four copper tacks driven 1½ inches from the top, into a cedar stub which is 4½ feet long, 18 inches of which are above ground, and painted black. The bench-mark is 10.17 feet above mean low water, and 4.27 feet above mean high water. It is 60 meters east-southeast from southeast corner of Wilson's saw-mill, and 19½ feet west of a small cedar tree. This tree has also four copper tacks driven into it 1.99 feet higher than the other bench-mark.

*Key West, Florida.*—The upper surface of the upper course of stones of the stone foundation of Fort Taylor, at the north-northwest corner of the gate, is 11.39 feet above mean low water, and 10.09 feet above mean high water.

*Tortugas, Florida.*—The upper surfaces of the sole stones of the seventh and eighth embrasures at Fort Jefferson, counting from the southeast bastion, are each 7.32 feet above mean low water, and 6.20 feet above mean high water. They are northeast from the light-house. A line cut into the side of the light-house is 5.722 feet below the other bench-mark.

*Pensacola, Florida.*—The bench-mark is made on a spout on the south side of a cistern at store-house No. 26, Warrington navy-yard, 7.81 feet above mean low water, and 6.81 feet above mean high water.

*Mobile, Alabama.*—The bench-mark is cut on a brick in the wall near the south corner of Government and Commerce streets, facing Commerce street, and 1.50 feet above the side-walk. It is 6.56 feet above mean low water, and 4.89 feet above mean high water.

*East Rigolet light-house, Lake Borgne, Louisiana.*—The bench-mark is the top surface of the lower stone step of the East Rigolet light-house. It is 10.92 feet above mean low water, and 9.91 feet above mean high water.

*Mississippi Delta, Louisiana.—South West Pass.—Pilot's Bayou.*—The bench-mark is a white cedar post, situated about 15 feet southwest from the house occupied by Charles Crown. The top of this post is about 18 inches out of the ground, and 3.1 feet above mean low water, and 2.0 feet above mean high water.

*San Diego, California.—La Plaza.*—The tidal bench-mark is 130 yards west ½ south from the place where the self-registering gauge was used, which is about one-eighth of a mile north of La Plaza. It is of granite, about 10 inches square on the top, and faced down about 14 inches on the sides. It is marked on the top with the letters U. S. On the west side it is marked, "For tides;" on the north side, "Ref. mark;" on the east side, "Coast Survey;" on the south side, "1853, '54, '55." It is now boxed, so that only 2 inches are exposed. It is 10.73 feet above mean low water, and 6.87 feet above mean high water.

*Fort Point, California.*—The principal bench-mark is at the government ordnance wharf, about 600 yards southeasterly from the fort at Fort Point, which overlooks the entrance to the bay of San Francisco. It was cut on one of the stones of the abutment of the wharf; and it is 7.78 feet above mean low water, and 3.98 feet above mean high water. It was also marked by a spike driven into a granite block in the foundation of and under the upper part of the wharf, near its land termination. About $87\frac{3}{4}$ feet southwesterly from the above bench-mark is another granite monument 8 inches square, 5.164 feet higher than the first marks, and just below the surface of the earth. About 230 feet westerly from the first is still another granite monument, 14 inches square, and 42.569 feet higher than the first. It is also just below the surface of the earth. The two last stones were firmly set on a concrete foundation. There are no marks upon them.

*Astoria, Oregon.*—The bench-mark is on the large rock at Astor Point, which is 10 or 12 feet high and almost square at the top, where it is 6 or 8 feet across. The mark was cut in horizontally with a chisel, about halfway up the side, and is concealed by very high tides. The rock lies a little above the government wharf built by the United States troops on the property of Mr. Welsh. The bench-mark is 8.26 feet above mean low water, and 2.25 feet above mean high water.

# APPENDIX No. 11.

EXTRACT FROM A REPORT TO PROFESSOR BENJAMIN PEIRCE, SUPERINTENDENT UNITED STATES COAST SURVEY, RELATIVE TO A METHOD OF DETERMINING ELEVATIONS ALONG THE COURSE OF A TIDAL RIVER, WITHOUT THE AID OF A LEVELING-INSTRUMENT.

In the course of my physical survey of the Hudson, I have reached the following method of measuring elevations from point to point, a method not yet thoroughly tested, but apparently very accurate as applied to the river now under examination, and very rapid:

Set up graduated staves at such distances apart that the slacks of the tidal currents shall extend from one to another. By simultaneous observations ascertain the difference in the readings of these gauges at the slack between ebb and flood currents, and again the difference at the slack between flood and ebb, then apply the—

RULE.—*The difference in the elevations of the zeros of the gauges is equal to one-half the sum of the differences of their readings at the two slack waters.*

The explanation of this simple rule is equally simple. In a tidal avenue having no fresh-water feeders, one will readily admit that the inertia-slopes at the two slacks will be equal and opposite. In a tidal river the observed slopes will also be equal, as measured from the horizontal; because the difference in the effects of the momenta of the two unequal drifts will balance the *river-slope*. By the term *river-slope*, I mean the inclination of the surface of the river as it would be if tideless.

You have called my attention to errors that must appear in the practical application of this rule to the case where the channel section varies from point to point; these I grant, but believe, in most cases, they must be inconsiderable. There are also small errors due to bends of the stream, to be canceled by a proper arrangement of stations, and errors resulting from "*diurnal inequality*," which may be canceled by a proper selection of dates, or by observing two pairs of slacks. My work comes out very well upon the Hudson, without taking any of these precautions; and I purpose to offer my rule as an addendum to my report on the "Reclamation of tide-lands," since it is likely to prove useful in connection with projects for the rectification of rivers, the weiring and diking of streams, &c.

In the Hudson, I found that staves ten miles apart could be referred to each other by this rule, and that no nice current-observations were really necessary. The slope is so nearly constant about the time of slack water, that an error in this time of a half hour, in some cases, would be of no consequence. The *coincidence of time* at the two gauges, and the careful reading of the heights, are the most important elements. I offer below an illustration from observations upon one of the fourteen reaches examined during the past month:

| Slack, ebb to flood. | | | | Slack, flood to ebb. | | | |
|---|---|---|---|---|---|---|---|
| Time. | Heights at Barnegat. | Heights at Poughkeepsie. | Difference. | Time. | Heights at Barnegat. | Heights at Poughkeepsie. | Difference. |
| *h. m.* | *Feet.* | *Feet.* | *Feet.* | *h. m.* | *Feet.* | *Feet.* | *Feet.* |
| 10 20 | 2.07 | 2.86 | 0.79 | 4 45 | 4.24 | 5.73 | 1.49 |
| 10 25 | 2.18 | 2.97 | 0.79 | 4 50 | 4.20 | 5.66 | 1.46 |
| 10 30 | 2.27 | 3.07 | 0.80 | 4 55 | 4.12 | 5.60 | 1.48 |
| 10 35 | 2.34 | 3.17 | 0.83 | 5 00 | 4.03 | 5.53 | 1.50 |
| 10 40 | 2.47 | 3.27 | 0.80 | 5 05 | 3.99 | 5.48 | 1.49 |
| 10 45 | 2.54 | 3.36 | 0.82 | 5 10 | 3.93 | 5.40 | 1.47 |
| | | | | 5 15 | 3.88 | 5.35 | 1.47 |
| | | | $a$=0.80 | 5 20 | 3.80 | 5.29 | 1.49 |
| | | | | | | | $b$=1.48 |

$\frac{1}{2}(a + b) = 1.14 =$ diff. of elevation of zeros of staves.
$\frac{1}{2}(b - a) = 0.34 =$ slope of surface at slack water.

The slope at slack water is opposed to the direction of the current which has just ceased; in other words, the water, by virtue of its inertia, runs up hill for some time before it is checked. In the case of the Hudson, the slacks occur near the time of half-tide, or when the surface of the stream is near its maximum inclination. In most of our harbors, the slacks occur near times of high and low water, when the surfaces are nearly horizontal.

In a later and fuller report I shall present a comparison of my results with those obtained from a line of levels previously run by officers of the Coast Survey along the Hudson River Railroad.

I sent a copy of the above notes to M. Stessels, hydrographic engineer of Belgium, who has been busy for several years, with distinguished success, upon a physical survey of the Scheldt (*L'Escaut.*) He responded immediately in a somewhat lengthy communication, and I feel bound to notice his criticisms, not only because I had designed to elicit objections, but also because his points are well stated. He says that my method is "very applicable in the lower part of the river, between Flessingue and Bath, owing to the small slope of surface during the slacks of flood and ebb; but higher up, I should have little confidence, owing to the variations in *the form of the diagram*, and of the anomalies which the general slope presents * * * * I consider it reliable so long as the slope remains small, *i. e.*, so long as the mass of fresh water has no influence upon the [form of the] tide."

This matter of the change of form in the tidal curve we have discussed, but without sufficient data as yet. I have supposed that my problem included this, but it remains to be seen.

Mr. Stessels closes his letter with the statement that "during the winter I have no means of making observations which I can direct in person, but in the spring I shall have the tide observed, during slack waters, between Bath and Lillo, where an abrupt contraction modifies greatly the tidal phenomena; and I shall take pleasure in communicating to you my results." I too, with your consent, shall extend my survey into the upper reaches of the Hudson, where the fresh water element is large and where crooks and turns of the channel are more frequent.

Very respectfully submitted.

HENRY MITCHELL,
*Chief Physical Hydrography, United States Coast Survey.*

Professor BENJAMIN PEIRCE,
*Superintendent United States Coast Survey.*

# APPENDIX No. 12.

## RESULTS OF THE TELEGRAPHIC DETERMINATION OF THE LONGITUDE OF SAN FRANCISCO, CAL.

The longitude campaign of 1869 between Cambridge, Massachusetts, and San Francisco, California, gave for the difference of longitude of the transit instruments at these stations $3^h\ 25^m\ 7^s.335 \pm 0^s.006$. This result is obtained: first, by a direct determination; second, by the intermediate station, Omaha; third, by the intermediate station, Salt Lake; and fourth, by the two intermediate stations Omaha and Salt Lake. The results here given are those from the first computation made by Mr. Isaac Bradford, and the probable errors take no account of the uncertainty of the personal equations. To refer the above difference of longitude from the west transit at Cambridge to the center of the dome of the observatory, we must add $0^s.04$. The resulting longitude for the Cambridge Observatory (dome) from the telegraphic determination of 1866, still employed at present, is $4^h\ 44^m\ 30^s.95$; hence telegraphic longitude of San Francisco astronomical station in Washington Square, $8^h\ 09^m\ 38^s.325$.

To compare our former results, depending on observations of moon-culminations, with the telegraphic result, we refer the latter geodetically to Presidio astronomic station, by application of the reduction $+ 10^s.81$.

Longitude of Presidio astronomic station by telegraph, $8^h\ 09^m\ 49^s.13$; same from fifty-one moon-culminations observed in 1852, $8^h\ 09^m\ 47^s.55 \pm 0^s.53$; and from forty-eight moon-culminations observed in 1852 at Telegraph Hill, and referred to Presidio astronomic station by the reduction $- 11^s.71$, the latter longitude becomes $8^h\ 09^m\ 46^s.91 \pm 0^s.66$. The mean by the moon-culminations ($8^h\ 09^m\ 47^s.23$) is therefore $1^s.90$ too small when compared with the telegraphic result, and this difference may be considered as representing $\frac{1.90}{30} = 0^s.06$, nearly, of personal equation, by which Assistant Davidson observed moon-culminations earlier than the Greenwich observers. The adopted geodetic longitude since 1852 was $8^h\ 09^m\ 45^s$, the result of twenty-one moon-culminations observed at Point Pinos in 1851, and of thirty-nine moon-culminations observed at Point Concep- tion in 1850, both referred chronometrically to Presidio.

Applying to the results of Mr. I. Bradford's computations the proper corrections due to differences of personal equations, and referring them to the dome at Cambridge, to the transits at Omaha and Salt Lake, and to the astronomical station in Washington Square at San Francisco, we have the following comparative differences of longitude between Cambridge and San Francisco:

| | | |
|---|---|---|
| 1. Cambridge to San Francisco direct | | $3^h\ 25^m\ 07^s.370 \pm 0^s.007$ |
| 2. Cambridge to Omaha | $1^h\ 39^m\ 15^s.069 \pm 0^s.008$ | |
| Omaha to San Francisco | 1 45 52 .294 ± 0 .010 | |
| | | 3 25 07 .363 ± 0 .013 |
| 3. Cambridge to Salt Lake | 2 43 04 .187 ± 0 .008 | |
| Salt Lake to San Francisco | 0 42 03 .204 ± 0 .008 | |
| | | 3 25 07 .391 ± 0 .011 |
| 4. Cambridge to Omaha | 1 39 15 .069 ± 0 .008 | |
| Omaha to Salt Lake | 1 03 49 .101 ± 0 .008 | |
| Salt Lake to San Francisco | 0 42 03 .204 ± 0 .008 | |
| | | 3 25 07 .374 ± 0 .014 |
| Resulting value | | 3 25 07 .375 ± 0 .006 |
| Telegraphic longitude of Cambridge, (dome) | | 4 44 30 .950 |
| Telegraphic longitude of San Francisco, (Washington Square) | | 8 09 38 .325 |

as stated above.

# APPENDIX No. 13.

ABSTRACT OF RESULTS FOR DIFFERENCE OF LONGITUDES BETWEEN THE HARVARD COLLEGE OBSERVATORY, CAMBRIDGE, MASSACHUSETTS, THE COAST SURVEY STATION, SEATON, ON CAPITOL HILL, AND THE UNITED STATES NAVAL OBSERVATORY, WASHINGTON, D. C., AS DETERMINED BY MEANS OF THE ELECTRIC TELEGRAPH, IN 1867, BY THE UNITED STATES COAST SURVEY, WITH THE CO-OPERATION OF PROFESSOR JOSEPH WINLOCK, DIRECTOR OF THE HARVARD OBSERVATORY, AND COMMODORE B. F. SANDS, U. S. N., SUPERINTENDENT NAVAL OBSERVATORY.

The difference of longitude between Washington and Cambridge has hitherto depended upon the early determinations of Sears C. Walker, esq. This value depended in part upon triangulation in consequence of there being at that time no telegraphic communication between New York and Jersey City, and the peculiar geological character of the valley of the Hudson River gave grounds for the suspicion of large station-errors. In Washington, also, the telegraphic connection had been made not directly with the Naval Observatory, but with a station upon Capitol Hill, some three miles from there. The superintendent accordingly determined, in 1867, to make a new determination of this important longitude, this time connecting the Naval Observatory station and the Cambridge Observatory directly together. The co-operation of the two prominent observatories was obtained, and the time was observed at these places by their own officers and according to their own methods.

At the Cambridge Observatory Mr. G. M. Searle observed for time with Simms transit, C. S. No. 8, of 44-inch focal length, 2¾-inch aperture and magnifying power 92. At the Seaton station Assistants G. W. Dean and E. Goodfellow observed for time with Thoughton & Simms transit, C. S. No. 4, of 46-inch focal length, 2¾-inch aperture, and magnifying power 96. At the Naval Observatory Professor S. Newcomb, Professor A. Hall, and Mr. C. Thirion observed for time with the transit circle belonging to the observatory. It has an aperture of 8½ inches, a focal length of 145 inches, and was used with a magnifying power of 186 diameters. Each station was furnished with a clock and a chronograph, and the method adopted for determining the differences of local times was that of direct clock comparisons, each observer putting his clock in the connecting circuit, in succession, and according to programme previously agreed upon. Transit observations were made before and after the exchange of clock signals. The distance, by wire, between Cambridge and Washington is four hundred and ninety-two statute miles, and between Seaton and the Naval Observatory at Washington about three miles. In the reduction of transits proper distinction was made between stars observed for instrumental corrections and stars observed for time. The adopted right ascensions of stars depend on Dr. Gould's Standard Places, second edition.

## 1. Difference of Longitude between the Cambridge and Washington Observatories.

At Cambridge the probable error of a clock correction by a single star is $\pm$ $0^s.08$. At Washington the transits by different observers are reduced to Professor Newcomb's standard of observing, and the personal equation between him and Mr. Searle is found to be $N - S = - 0^s.06 \pm .005$; a correction is applied for difference of personal equations to the Cambridge clock corrections, to give them as if they had been determined by Professor Newcomb. The probable error of a clock correction by a single star is $\pm$ $0^s.04$.

The following tables contain the differences of times $(\lambda - x)$ deduced from the comparisons of eastern clock signals and the difference of times $(\lambda + x)$ from the western clock signals.

(*a.*) *Differences of times from the Cambridge clock signals.*

| Date. | Approximate sidereal time at— Cambridge. | Approximate sidereal time at— Washington. | Differences of clocks. $T-T'$ | Clock corrections at— Cambridge. | Clock corrections at— Washington. | Differences of corrections. $\Delta T-\Delta T'$ | Differences of time. $\lambda-x$. | Probable error. |
|---|---|---|---|---|---|---|---|---|
| 1867. | *h. m.* | *h. m.* | *m. s.* | *s.* | *s.* | *s.* | *m. s.* | *s.* |
| June 4 | 14 55.1 | 14 31.0 | 24 06.08 | −18.38 | +6.49 | −24.87 | 23 41.21 | |
| | 15 05.4 | 14 41.3 | 06.00 | −18.38 | +6.49 | −27.87 | 41.13 | |
| | | | | | | | 23 41.17 | ±0.06 |
| 6 | 15 42.9 | 15 18.8 | 24 05.29 | −17.60 | +6.68 | −24.28 | 23 41.01 | |
| | 17 09.1 | 16 45.0 | 05.30 | −17.69 | +6.68 | −24.37 | 40.93 | |
| | 17 22.1 | 16 58.0 | 05.30 | −17.70 | +6.68 | −24.38 | 40.92 | |
| | | | | | | | 23 40.95 | ±0.03 |
| 10 | 16 42.1 | 16 18.0 | 24 06.23 | −18.22 | +6.96 | −25.18 | 23 41.05 | |
| | 17 39.1 | 17 15.0 | 06.21 | −18.16 | +6.96 | −25.12 | 41.09 | |
| | | | | | | | 23 41.07 | ±0.03 |
| 11 | 15 21.1 | 14 57.0 | 24 06.27 | −18.22 | +7.02 | −25.24 | 23 41.03 | |
| | 17 12.1 | 16 48.0 | 06.24 | −18.22 | +6.97 | −25.19 | 41.05 | |
| | | | | | | | 23 41.04 | ±0.03 |

(*b.*) *Differences of times from the Washington clock signals.*

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | $\lambda+x$ | |
| June 4 | 15 24.1 | 15 00.0 | 24 06.19 | −18.39 | +6.46 | −24.85 | 23 41.34 | |
| | 17 34.1 | 17 10.0 | 06.09 | −18.43 | +6.33 | −24.76 | 41.33 | |
| | | | | | | | 23 41.33 | ±0.06 |
| 6 | 15 26.1 | 15 02.0 | 24 05.46 | −17.58 | +6.68 | −24.26 | 23 41.20 | |
| | 17 46.1 | 17 22.0 | 05.41 | −17.72 | +6.69 | −24.41 | 41.00 | |
| | | | | | | | 23 41.10 | ±0.03 |
| 10 | 16 12.1 | 15 48.0 | 24 06.37 | −18.25 | +6.96 | −25.21 | 23 41.16 | |
| | 17 48.6 | 17 24.5 | 06.37 | −18.16 | +6.96 | −25.12 | 41.25 | |
| | | | | | | | 23 41.20 | ±0.03 |
| 11 | 15 50.5 | 15 26.4 | 24 06.40 | −18.21 | +7.00 | −25.21 | 23 41.19 | |
| | 17 32.1 | 17 08.0 | 06 38 | −18.22 | +6.97 | −25.19 | 41.19 | |
| | | | | | | | 23 41.19 | ±0.03 |

(*c.*) ***Resulting differences of longitude between the Cambridge and Washington observatories.***

| Date. | Difference of times from— Eastern signals. | Difference of times from— Western signals. | Difference or double retardation. | Resulting difference of longitude. |
|---|---|---|---|---|
| 1867. | *m. s.* | *m. s.* | *s.* | *m. s.* |
| June 4 | 23 41.17 | 23 41.33 | 0.16 | 23 41.25 |
| 6 | 23 40.95 | 41.10 | 0.15 | 41.03 |
| 10 | 23 41.07 | 41.20 | 0.13 | 41.13 |
| 11 | 23 41.04 | 41.19 | 0.15 | 41.12 |
| Mean | | | | 23 41.13 ± 0.03 |

**Reduction from west transit to center of dome at Cambridge, —0ˢ.021, and at Washington, —0ˢ.033; difference, —0ˢ.01. Resulting difference of longitude, Cambridge and Washington observatories, centers of domes, 23ᵐ 41ˢ.12 ± 0ˢ.03.**

0.039ˢ See Description of Station 1895-1901. Also Mr. Schott's Math. R. vol. 8, [illegible]

## 2. Difference of Longitude between the Cambridge Observatory and Seaton Station on Capitol Hill, Washington.

At Seaton, the probable error of a clock correction from a single star is ± 0.06; the results presented below are corrected for difference of personal equation, the Seaton observations are referred to Searle by the comparisons D. — S. = $-0^s.042 \pm 0^s.007$ and G. — S. = $+0^s.041 \pm 0.006$ as deduced from observations June 19, 20, 27, 1867.

*(a.) Differences of times from the Cambridge clock-signals.*

| Date. | Approximate sidereal time at— Cambridge. | Approximate sidereal time at— Seaton. | Differences of clocks, T − T′ | Clock corrections at— Cambridge. | Clock corrections at— Seaton. | Differences of corrections. ΔT − ΔT′ | Differences of time. λ − x | Probable error. |
|---|---|---|---|---|---|---|---|---|
| 1867. | *h. m.* | *h. m.* | *m. s.* | *s.* | *s.* | *s.* | *m. s.* | *s.* |
| June 4 | 15 04.0 | 14 40.1 | 23 54.20 | −18.45 | +7.28 | −25.73 | 23 28.47 | |
| | 17 21.0 | 16 57.1 | 54.19 | −18.49 | +7.19 | −25.68 | 28.51 | |
| | | | | | | | 23 28.49 | ±0.06 |
| 5 | 14 43.0 | 14 19.1 | 23 54.04 | −18.25 | +7.48 | −25.73 | 23 28.31 | |
| | 17 08.1 | 16 44.2 | 54.00 | −18.27 | +7.32 | −25.59 | 28.41 | |
| | | | | | | | 23 28.36 | ±0.03 |
| 6 | 14 58.4 | 14 34.5 | 23 53.34 | −17.62 | +7.31 | −24.93 | 23 28.41 | |
| | 15 43.9 | 15 20.0 | 53.30 | −17.66 | +7.30 | −24.96 | 28.34 | |
| | 17 22.9 | 16 59.0 | 53.21 | −17.76 | +7.26 | −25.02 | 28.19 | |
| | | | | | | | 23 28.31 | ±0.03 |
| 10 | 15 25.9 | 15 02.0 | 23 50.77 | −18.35 | +4.08 | −22.43 | 23 28.34 | |
| | 17 36.9 | 17 13.0 | 50.70 | −18.21 | +4.09 | −22.30 | 28.40 | |
| | | | | | | | 23 28.37 | ±0.03 |
| 11 | 15 22.0 | 14 58.2 | 23 51.02 | −18.28 | +4.32 | −22.60 | 23 28.42 | |
| | 17 13.0 | 16 49.1 | 51.00 | −18.28 | +4.27 | −22.55 | 28.45 | |
| | | | | | | | 23 28.43 | ±0.03 |
| 14 | 16 05.1 | 15 41.2 | 23 51.21 | −17.80 | +5.12 | −22.92 | 23 28.29 | |
| | 17 51.9 | 17 28.0 | 51.20 | −17.88 | +5.09 | −22.97 | 28.23 | |
| | | | | | | | 23 28.26 | ±0.03 |

*(b.) Differences of times from the Seaton clock-signals.*

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | λ + x | |
| June 4 | 15 13.9 | 14 50.0 | 23 54.34 | −18.45 | +7.27 | −15.72 | 23 28.62 | |
| | 17 26.9 | 17 03.0 | 54.28 | −18.49 | +7.19 | −15.68 | 28.60 | |
| | | | | | | | 23 28.61 | ±0.06 |
| 5 | 14 54.9 | 14 31.0 | 23 54.14 | −18.25 | +7.47 | −25.72 | 23 28.42 | |
| | 17 15.9 | 16 52.0 | 54.07 | −18.27 | +7.31 | −25.58 | 28.49 | |
| | | | | | | | 23 28.46 | ±0.03 |
| 6 | 15 18.9 | 14 55.0 | 23 53.48 | −17.64 | +7.30 | −24.94 | 23 28.54 | |
| | 17 38.9 | 17 15.0 | 53.41 | −17 78 | +7.26 | −25.04 | 28.37 | |
| | | | | | | | 23 28.45 | ±0.03 |
| 10 | 16 02.8 | 15 39.0 | 23 50.89 | −18.32 | +4.08 | −22.40 | 23 28.49 | |
| | 17 43.8 | 17 20.0 | 50.81 | −18.20 | +4.09 | −22.29 | 28.52 | |
| | | | | | | | 23 28 50 | ±0.03 |
| 11 | 15 43.8 | 15 20.0 | 23 51.17 | −18.28 | +4.31 | −22.59 | 23 28.58 | |
| | 17 25.8 | 17 02.0 | 51.11 | −18.28 | +4.26 | −22.54 | 28.57 | |
| | | | | | | | 23 28.57 | ±0.03 |
| 14 | 16 22.8 | 15 59.0 | 23 51.37 | −17.82 | +5.11 | −22.93 | 23 28.44 | |
| | 18 04.8 | 17 41.0 | 51.33 | −17.90 | +5.09 | −22.99 | 28.34 | |
| | | | | | | | 23 28.39 | ±0.03 |

*(c.) Resulting difference of longitude between the Cambridge Observatory and Seaton Station.*

| Date. | Difference of times from— Eastern signals. | Western signals. | Difference or double retardation. | Resulting difference of longitude. |
|---|---|---|---|---|
| 1867. | *m. s.* | *m. s.* | *s.* | *m. s.* |
| June 4 | 23 28.49 | 23 28.61 | 0.12 | 23 28.55 |
| 5 | 28.36 | 28.46 | 0.10 | 28.41 |
| 6 | 28.31 | 28.45 | 0.14 | 28.38 |
| 10 | 28.37 | 28.50 | 0.13 | 28.44 |
| 11 | 28.43 | 28.57 | 0.14 | 28.50 |
| 14 | 28.26 | 28.39 | 0.13 | 28.33 |
| Mean | | | | 23 28.44 ± 0.02 |

When referred to the center of dome of Cambridge Observatory, this difference becomes $23^m$ $28^s.46 \pm 0.02$.

### 3. Difference of Longitude between the Seaton Station and the Naval Observatory at Washington.

The observations for clock corrections on the 6th and 11th of June are by Mr. Goodfellow, and the results are referred to the standard of observation of Mr. Dean by means of the relation D. — G. = — $0^s.025 \pm 0^s.010$, as found at Seaton on July 1. The clock corrections are next referred to the standard of observation by Professor Newcomb by means of the difference of personal equations D. — N. = + $0^s.018 \pm 0^s.008$, as determined through the intermediation of Mr. Searle, June 19 and 21, and July 1.

*(a.) Differences of times from the Seaton clock-signals.*

| Date. | Approximate sidereal time at— Seaton. | Naval Obs'y. | Differences of clocks, T − T′ | Clock corrections at— Seaton. | Naval Obs'y. | Differences of corrections. ΔT − ΔT′ | Differences of time. λ − x | Probable error. |
|---|---|---|---|---|---|---|---|---|
| 1867. | *h. m.* | *h. m.* | *m. s.* | *s.* | *s.* | *s.* | *m. s.* | *s.* |
| June 4 | 14 50.0 | 14 49.8 | 0 11.80 | +7.33 | +6.48 | + 0.85 | 0 12.65 | |
| | 17 05.0 | 17 04.8 | 11.80 | +7.24 | +6.34 | + 0.90 | 12.70 | |
| | | | | | | | 0 12.67 | ±0.03 |
| 6 | 14 57.0 | 14 56.8 | 0 12.00 | +7.30 | +6.68 | + 0.62 | 0 12.62 | |
| | 17 15.0 | 17 14.8 | 12.00 | +7.26 | +6.68 | + 0.58 | 12.58 | |
| | | | | | | | 0 12.60 | ±0.03 |
| 10 | 15 40.0 | 15 39.7 | 0 15.48 | +4.14 | +6.96 | − 2.82 | 0 12.66 | |
| | 17 20.0 | 17 19.7 | 15.53 | +4.15 | +6.96 | − 2.81 | 12.72 | |
| | | | | | | | 0 12.69 | ±0.03 |
| 11 | 15 20.0 | 15 19.7 | 0 15.25 | +4.37 | +7.00 | − 2.63 | 0 12.62 | |
| | 17 05.0 | 17 04.7 | 15.24 | +4.32 | +6.96 | − 2.64 | 12.60 | |
| | | | | | | | 0 12.61 | ±0.03 |
| 21 | 18 20.0 | 18 19.7 | 0 19.00 | +1.54 | +7.85 | − 6.31 | 0 12.69 | ±0.03 |
| 29 | 16 40.0 | 16 39.6 | 0 25.11 | −3.24 | +9.22 | −12.46 | 0 12.65 | |
| | 18 45.0 | 18 44.6 | 25.20 | −3.27 | +9.20 | −12.47 | 12.73 | |
| | | | | | | | 0 12.69 | ±0.03 |

*(b.) Differences of times from the Naval Observatory clock-signals.*

| Date. | Approximate sidereal time at— | | Differences of clocks, T−T′. | Clock corrections at— | | Differences of corrections, ΔT−ΔT′. | Differences of time, λ −x. | Probable error. |
|---|---|---|---|---|---|---|---|---|
| | Seaton. | Naval Obs'y. | | Seaton. | Naval Obs'y. | | | |
| 1867. | h. m. | h. m. | m. s. | s. | s. | s. | m. s. | s. |
| June 4 | 15 04.2 | 15 04.0 | 0 11.83 | +7.32 | +6.47 | + 0.85 | 0 12.68 | |
| | 17 08.2 | 17 08.0 | 11.82 | +7.24 | +6.34 | + 0.90 | 12.72 | |
| | | | | | | | 0 12.70 | ±0.03 |
| 6 | 15 01.2 | 15 01.0 | 0 12.00 | +7.30 | +6.68 | + 0.62 | 0 12.62 | |
| | 17 23.2 | 17 23.0 | 12.00 | +7.26 | +6.68 | + 0.58 | 12.58 | |
| | | | | | | | 0 12.60 | ±0.03 |
| 10 | 15 48.2 | 15 48.0 | 0 15.49 | +4.14 | +6.96 | − 2.82 | 0 12.67 | |
| | 17 24.2 | 17 24.0 | 15.54 | +4.15 | +6.96 | − 2.81 | 12.73 | |
| | | | | | | | 0 12.70 | ±0.03 |
| 11 | 15 25.2 | 15 26.0 | 0 15.27 | +4.37 | +7.00 | − 2.63 | 0 12.64 | |
| | 17 10.2 | 17 10.0 | 15.27 | +4.32 | +6.96 | − 2.64 | 12.63 | |
| | | | | | | | 0 12.63 | ±0.03 |
| 21 | 16 52.3 | 16 52.0 | 0 19.00 | +1.60 | +7.88 | − 6.28 | 0 12.72 | |
| | 18 25.3 | 18 25.0 | 19.10 | +1.54 | +7.85 | − 6.31 | 12.79 | |
| | | | | | | | 0 12.75 | ±0.03 |
| 29 | 16 46.4 | 16 46.0 | 0 25.10 | −3.24 | +9.22 | −12.46 | 0 12.64 | |
| | 18 47.4 | 18 47.0 | 25.20 | −3.27 | +9.20 | −12.47 | 12.73 | |
| | | | | | | | 0 12.68 | ±0.03 |

*(c.) Resulting difference of longitude between the Seaton station and the Naval Observatory at Washington.*

| Date. | Difference of times from— | | Difference, or double retardation. | Resulting difference of longitude. |
|---|---|---|---|---|
| | Eastern signals. | Western signals. | | |
| 1867. | m. s. | m. s. | s. | m. s. |
| June 4 | 0 12.67 | 0 12.70 | + 0.03 | 0 12.68 |
| 6 | 12.60 | 12.60 | 0.00 | 12.60 |
| 10 | 12.69 | 12.70 | + 0.01 | 12.69 |
| 11 | 12.61 | 12.63 | + 0.02 | 12.62 |
| 21 | 12.69 | 12.75 | + 0.06 | 12.72 |
| 29 | 12.69 | 12.68 | − 0.01 | 12.69 |
| Mean | | | | 0 12.67±0.01 |

When reduced to center of dome of Naval Observatory, the resulting difference of longitude becomes, $0^m\ 12^s.64 \pm 0^s.01$.

Adding the two parts, they are found $0^s.02$ smaller than the whole, which has consequently been diminished by $0^s.01$, and the first part has been increased by the same amount; we have, therefore, the final results:

1. Difference of longitude between the centers of domes of the Harvard College Observatory, Cambridge, and the United States Naval Observatory, Washington, D. C.: $0^h\ 23^m\ 41^s.11 \pm 0^s.03$.

2. Difference of longitude between the center of dome of the Harvard College Observatory, Cambridge, and the Coast Survey station Seaton, at Washington: $0^h\ 23^m\ 28^s.47 \pm 0^s.03$.

3. Difference of longitude between the Coast Survey station Seaton and the United States Naval Observatory, center of dome, at Washington: $0^h\ 0^m\ 12^s.64 \pm 0^s.02$.

The probable errors of the last two results are increased by $0^s.01$ to take in the uncertainty in the personal equations.

# APPENDIX No. 14.

NEW INVESTIGATION OF THE SECULAR CHANGES IN THE DECLINATION, THE DIP, AND THE INTENSITY OF THE MAGNETIC FORCE, AT WASHINGTON, D. C. [REPORT TO THE ASSISTANT IN CHARGE OF THE OFFICE, BY CHARLES A. SCHOTT, ASSISTANT.]

JUNE 30, 1873.

The magnetic observations at Washington, which are kept up chiefly for the purpose of ascertaining the annual changes, and of furnishing a base-station at which magnetic instruments may be tested and their results compared, extend at this time over a sufficient range of years to make it desirable to submit them to a new scrutiny respecting the secular progression.

Nearly fourteen years have passed since the last general discussion of the secular change of the declination,* and now twelve new values of the declination have been added to the six previously available.

Since the last discussion of the secular changes in the dip,† a reversal in the direction of the motion has taken place, in consequence of which unexpected change, the formulæ, constructed seventeen years ago, no longer apply. In the place of seven observations, we have now twenty-four available for the new discussion, but the time covered by these observations is yet too short to admit of the introduction of a periodic function to express the secular change.

Respecting the change in the horizontal force, it was, in 1861,‡ only possible to indicate the fact that the horizontal force for places on our Atlantic coast had then for some years been slowly decreasing, and to point out, approximately, the annual amount. We have now nineteen observations in the place of thirteen in 1861, and are enabled to indicate the law of change during the period of observation. The horizontal force and the dip became stationary about the same time, and the former is now slowly increasing, while the latter is slightly decreasing.

The observations in the District of Columbia extend as far back as 1792, for the declination, but the earliest record I could find of the dip is of 1839, and of the horizontal force, of 1842.

The greater number of observations were made on Capitol Hill, and all within the lines of the District. Special references to locality and observer and remarks will be found in Coast Survey Report for 1869, Appendix No. 9, pp. 199–207. The observations, commenced at my garden on Capitol Hill in 1867, have been continued to date. In the spring of 1873 the observatory was moved four meters to the northward, to be clear of local attraction in the vicinity.

*Secular change in the magnetic declination.*—Combining to a mean value the two results of 1792, as found inscribed on the eastern corner-stone of the District, and on the first mile-stone to the northwest of it, and omitting the value given on the fourth mile-stone as too discordant, and assigning to the observation of 1809 the weight one-half, all others having the weight one, the declinations have been represented by the formula—

$$D = +1^\circ.79 + 1^\circ.90 \sin (1.5\,n - 24^\circ.1)$$

where $n$ = number of years elapsed since 1830, and D = magnetic declination, + when west, and expressed in degrees. The accordance between the observed and computed values is shown in the following table:

| Date. | Observed declination. | Computed declination. | Difference, O. − C. | Date. | Observed declination. | Computed declination. | Difference, O. − C. |
|---|---|---|---|---|---|---|---|
| | ° | ° | ° | | ° | ° | ° |
| 1792.5 | − 0.24 | − 0.08 | − 0.16 | 1863.6 | + 2.70 | + 2.63 | + 0.07 |
| 1809.0 | + 0.87 | + 0.22 | + 0.65 | 1866.8 | + 2.74 | + 2.77 | − 0.03 |
| 1841.0 | + 1.34 | + 1.54 | − 0.20 | 1867.5 | + 2.80 | + 2.80 | 0.00 |
| 1842.0 | + 1.40 | + 1.59 | − 0.19 | 1868.5 | + 2.85 | + 2.84 | + 0.01 |
| 1855.5 | + 2.40 | + 2.25 | + 0.15 | 1869.3 | + 2.88 | + 2.87 | + 0.01 |
| 1856.6 | + 2.36 | + 2.30 | + 0.06 | 1870.5 | + 2.89 | + 2.92 | − 0.03 |
| 1857.2 | + 2.41 | + 2.34 | + 0.07 | 1871.5 | + 2.95 | + 2.96 | − 0.01 |
| 1860.7 | + 2.44 | + 2.50 | − 0.06 | 1872.5 | + 3.00 | + 3.00 | 0.00 |
| 1862.7 | + 2.66 | + 2.59 | + 0.07 | 1873.5 | + 3.00 | + 3.02 | − 0.02 |

* Coast Survey Report of 1859, Appendix No. 24, pp. 296–305. The first discussion is given in the report for 1855, Appendix No. 48, pp. 306–337.

† Coast Survey Report for 1856, Appendix No. 32, pp. 235–245; also Appendix No. 33, pp. 246–249.

‡ Coast Survey Report for 1861, Appendix No. 22, pp. 242–251.

The probable error of a single representation is $\varepsilon_0 = \pm 4'.9$; for the last seven years the accordance is better, for the reason that all observations were made at the same spot (excepting the small shift in 1873.) It is well known that the local disturbances in the distribution of magnetism within the District are of considerable magnitude.

The annual variation $v$ is given by: $v = + 2'.985 \sin (1.5\, n + 66^\circ)$.

The epoch of the last minimum (*west* declination) is found to be 1786, when $D = -0^\circ.11$. The curve of no-declination, about the close of the last century, consequently passed to the northeast of Washington.* It is probable that the declination will continue to increase, though with a diminishing rate, to the close of the century. The following table contains decennial values computed by the preceeding formula.

| Year. | Declination. | Year. | Declination. |
|---|---|---|---|
| | ° | | ° |
| 1790 | −0.10 | 1840 | +1.49 |
| 1800 | +0.02 | 1850 | +1.98 |
| 1810 | +0.25 | 1860 | +2.47 |
| 1820 | +0.59 | 1870 | +2.90 |
| 1830 | +1.01 | 1880 | +3.27 |

Annual increase in 1870, 2'.4, and in 1880, 1'.9.

*Secular change in the magnetic dip.*—Of twenty-seven collected results only two were rejected on account of discordance, (one of 1845 and one of 1866, when the results may have been affected either by local attractions or by defective needles,) and after uniting two sets of observations with different needles, in 1871, there remained for discussion twenty-four values. My paper on the secular change of the dip, written in 1856, led to the fixation of an epoch of *minimum* dip in the year 1842; the observations made at Washington in 1860 first indicated a change in the direction of the annual progressive motion which was confirmed by the observations taken at Eastport, Maine, and at Toronto, Canada. Supposing the dip to have been generally diminishing, the existence of a subordinate period of short duration appears to be indicated, which for a short time produced a small increase in the dip, the former diminution being afterwards re-established.

The observations have been represented by the formula—

$$I = 71^\circ.335 - 0.000229\,(t - 1855.0) - 0.000640\,(t - 1855.0)^2 - 0.0000303\,(t - 1855.0)^3$$

| Date. | Observed dip. | Computed dip. | Difference, O.—C. | Date. | Observed dip. | Computed dip. | Difference, O.—C. |
|---|---|---|---|---|---|---|---|
| | ° | ° | ° | | ° | ° | ° |
| 1839.2...... | 71.29 | 71.30 | − 0.01 | 1860.6....... | 71.27 | 71.31 | − 0.04 |
| 1841.0...... | 71.30 | 71.29 | + 0.01 | 1861.6....... | 71.30 | 71.30 | 0.00 |
| 1842.5...... | 71.23 | 71.30 | − 0.07 | 1862.6....... | 71.30 | 71.28 | + 0.02 |
| 1844.4...... | 71.27 | 71.30 | − 0.03 | 1863.5....... | 71.24 | 71.27 | − 0.03 |
| 1851.5...... | 71.32 | 71.33 | − 0.01 | 1865.5....... | 71.20 | 71.23 | − 0.03 |
| 1852.4...... | 71.38 | 71.33 | + 0.05 | 1867.5....... | 71.11 | 71.17 | − 0.06 |
| 1853.4...... | 71.36 | 71.33 | + 0.03 | 1868.5....... | 71.06 | 71.14 | − 0.08 |
| 1855.7...... | 71.47 | 71.34 | + 0.13 | 1869.3....... | 70.97 | 71.11 | − 0.14 |
| 1856.6...... | 71.34 | 71.33 | + 0.01 | 1870.5....... | 70.92 | 71.06 | − 0.14 |
| 1857.2...... | 71.38 | 71.33 | + 0.05 | 1871.4....... | 71.00 | 71.03 | − 0.03 |
| 1858.4...... | 71.38 | 71.33 | + 0.05 | 1872.5....... | 71.00 | 70.97 | + 0.03 |
| 1859.5...... | 71.41 | 71.32 | + 0.09 | 1873.5....... | 70.97 | 70.92 | + 0.05 |

The probable error of a single representation is about $\pm 2'.5$. The annual change is derived from:

$$dI = -0.00023\, dt - 0.00128\,(t - 1855)\, dt - 0.00009\,(t - 1855)^2\, dt$$

and replacing $dt$ by unity, for 1873.5 the annual change becomes $-0^\circ.055$ or $-3'.3$. The maximum dip, according to the formula, occurred about 1854.8.

* The magnetic chart for 1870, in Coast Survey Report for 1865, exhibits the position of the isogonic line of no-declination as passing between Washington and Baltimore in 1801.

*Secular change in the horizontal force.*—There are nineteen values of the horizontal component of the magnetic intensity, one only having been omitted, that of 1855, on account of discordance; (it was observed at a spot where the declination was found to be deflected $3\frac{1}{8}°$.) For the last sixteen years the horizontal force has been steadily on the increase, while at the same time the dip has been diminishing, thus leaving the total intensity but slightly affected.

The horizontal force is represented by the formula:

$$H = 4.270 + 0.00084\ (t—1855.0) + 0.000248\ (t—1855.0)^2$$

The observed and computed values compare as follows:

| Date. | Observed horizontal force. | Computed horizontal force. | Difference, O. — C. | Date. | Observed horizontal force. | Computed horizontal force. | Difference, O. — C. |
|---|---|---|---|---|---|---|---|
| 1842.5 | 4.347 | 4.299 | +.048 | 1863.6 | .282 | .296 | −.014 |
| 1844.5 | .292 | .289 | +.003 | 1866.8 | .300 | .315 | −.015 |
| 1845.5 | .237 | .285 | −.048 | 1867.5 | .321 | .320 | +.001 |
| 1851.5 | .229 | .270 | −.041 | 1868.5 | .334 | .327 | +.007 |
| 1855.7 | .250 | .271 | −.021 | 1869.3 | .347 | .333 | +.014 |
| 1856.7 | .308 | .273 | +.035 | 1870.5 | .352 | .343 | +.009 |
| 1858.3 | .255 | .276 | −.021 | 1871.5 | .356 | .352 | +.004 |
| 1859.6 | .307 | .279 | +.028 | 1872.5 | .360 | .361 | −.001 |
| 1860.7 | .319 | .283 | +.036 | 1873.5 | .344 | .371 | −.027 |
| 1862.5 | 4.292 | 4.291 | +.001 | | | | |

The probable error of a single representation is ± 0.018. The annual change is derived from

$$dH = +\ 0.00084\ dt + 0.000496\ (t—1855)\ dt$$

and replacing $dt$ by unity. We find $dH$ for 1873.5, + 0.010, which equals $\frac{1}{436}$ of the horizontal force. The minimum occurred about 1853.3.

*Secular change in the total force.*—For many years past the secular change in the magnetic intensity was so insignificant that its existence could hardly be detected, and at the same time was so overlaid with the observing errors in the dip and horizontal force that the computed values of the total force exhibited large discordances. For some time past the decreasing dip was less effective on the total force than the increasing horizontal force, leaving as residual motion a slowly increasing total force; which, however, now appears to have become nearly stationary.

Using the preceding formulæ for I and H, and computing the total force F by the relation—

$$F = H \sec I$$

we form the following table of decennial values:

| Date. | I. | H. | F. |
|---|---|---|---|
| | ° | | |
| 1842.5 | 71.30 | 4.299 | 13.41 |
| 1852.5 | 71.33 | 4.270 | 13.34 |
| 1862.5 | 71.28 | 4.291 | 13.370 |
| 1872.5 | 70.97 | 4.361 | 13.375 |

It would appear that the total force reached a minimum about twenty-two years ago, has since that time been slowly on the increase, and is at present almost stationary, probably decreasing again. At Toronto, since 1849, the total force has generally been on the decrease, but between 1860 and 1868 it may be said to have been almost constant.*

We have:

$$dF = \sec I\ dH + F \tan I \sin 1'\ dI, \quad \text{where } dI \text{ is to be expressed in minutes.}$$

For 1873.5, at Washington: $dH = +\ 0.010$, $dI = —3.3$; hence annual change of total force, or $dF = —0.006$.

The hypothesis that the observed secular change is the effect of thermal changes in the earth's crust, manifesting itself as a *disturbance* in the distribution of terrestrial magnetism, seems to me a

* Monthly absolute values of the magnetic elements at Toronto, from 1865 to 1868, inclusive, &c., &c., by G. T. Kingston, M. A., director of the magnetic observatory.

plausible one; these thermal changes must be considered to have a slow rate but operating on a vast scale, thus explaining the similarity of secular change extending over thousands of miles, and going on perhaps for hundreds of years. As far as observed they appear of a mixed progressive and periodic character. Such thermal surfaces of equal heat may propagate themselves in any direction, and may be supposed compounded of a number of separate waves having different directions and periods, and producing corresponding effects on the magnetic declination, dip, and intensity. They are supposed, ultimately, to owe their origin to a transfer of matter disturbing the equilibrium of temperature and magnetism.

Thus the influence which produced the increase of the magnetic *west* declination on our Atlantic coast was first recognized in the northeast, extending itself in time toward the southwest; the *minimum west* declination occurred at Portland, Maine, about 1765, at Cambridge, Massachusetts, about 1783, at New York about 1795, at Savannah, Georgia, about 1817, at New Orleans, Louisiana, about 1831, and at the City of Mexico about 1838, appearing at the last three places as a *maximum* of east declination. The same influence will, possibly, soon reach our Pacific coast, where, at present, the east declination is still slowly on the increase. Sub-periods or subordinate waves in the secular change have been recognized in the observed declinations at Cambridge, Massachusetts, at Hatboro, Pennsylvania, (near Philadelphia,) and other places, and they are also noted in the observed dips at Washington, and Toronto, Canada.

Taking this view of the subject the phenomenon of the secular change is a complex one, and the numerical formulæ designed for expressing it must, for the present, retain their tentative and hence provisional character, and they should not be used (either way) much beyond the time for which they are supported by observations.

# APPENDIX No. 15.

RESULTS OF OBSERVATIONS FOR DAILY VARIATION OF THE MAGNETIC DECLINATION, MADE AT FORT STEILACOOM, WASHINGTON TERRITORY, IN 1866, AND AT CAMP DATE CREEK, ARIZONA, IN 1867, BY DAVID WALKER, M. D., ACTING ASSISTANT SURGEON, UNITED STATES ARMY. [DISCUSSED AND REPORTED TO THE ASSISTANT IN CHARGE OF THE COAST SURVEY OFFICE, BY CHARLES A. SCHOTT, ASSISTANT COAST SURVEY.]

A duplicate record of these observations was presented to the Coast Survey Office by Dr. Walker, under date of July 10, 1871, with the request that they be discussed and published, if found of sufficient value.

The observations comprise hourly differential readings of the position of a horizontal magnetic needle at Fort Steilacoom, Washington Territory, from June 5 to August 31, 1866, and at Camp Date Creek, Arizona, from July 16 to November 26, 1867. The magnet was suspended by a fine untwisted thread of silk, adjusted to the normal direction of the magnetic meridian at each place. No special observations for torsion were made.

The observations appear to have been carefully made, and are without a break in their continuity; an assistant observer acted under Dr. Walker's immediate supervision.

The value of such observations depends greatly upon their remoteness from other magnetic stations where the magnetic laws have already been made out, and in the present case they will enable us to extend our knowledge of the daily variation over a large area previously unknown in this respect. The nearest stations where the laws of the daily variation have been studied from observations extending over a series of years are Toronto, Canada; Philadelphia, Pennsylvania; Key West, Florida; and Sitka, Alaska. The two stations, Fort Steilacoom and Camp Date Creek, are about 1,030 miles apart, and the latter is at an elevation of over 3,700 feet above the sea-level, which fact gives additional interest to the results.

It was deemed unnecessary to reproduce the individual readings, (they are deposited in the Coast Survey archives,) but it should be stated that during the period covered no unusually large disturbances occurred; on the contrary, the needle appears to have gone through its movements with great regularity, for which reason no discussion of disturbances has been attempted, and no readings have been excluded from the monthly means.

The geographical position of Fort Steilacoom I determine as follows: From the Coast Survey reconnaissance of Steilacoom Harbor, by Lieutenant Commanding J. Alden, United States Navy, in 1856, it appears that the center of the parade ground is about 0′.68 north and 1′.83 east of the Methodist Church in Steilacoom village; the latter position, by triangulation, is in latitude 47° 10′ 20″ and in longitude 122° 35′ 50″, hence, position of the fort, latitude 47° 11′ 01″ and longitude 122° 34′ 00″ west of Greenwich. Its elevation above the sea-level is stated by Dr. Walker to be 250 feet. The magnetic declination was 21° 30′ east, in 1856, as communicated by S. Garfield, surveyor-general of Washington Territory, and probably reached 22° 00′ east, in 1866, the estimated annual increase being nearly 3′. The magnetic dip may be estimated at 70¾°. The instrument was mounted and adjusted in position at 10 a. m., June 5; it was 4½ feet above ground, in a location supposed free from any local attraction, and on a level prairie; soil—sandy gravel. The value of one division of the scale is 1′.006, as determined at Kew; it appears, however, that at Fort Steilacoom and at Camp Date Creek these divisions were recorded as tenths, the proper value for these records is consequently 10′.06.

The geographical position of Camp Date Creek is variously given and subject to much uncertainty in the absence of any (known) astronomical observations: The meteorological reports at the Surgeon General's Office place it in latitude 34° 45′ and in longitude 112° 18′. On Colton's new atlas, (edition of 1873,) it is situated in latitude 34° 16′ and in longitude 112° 52′, and on the United States Engineers' map, issued by the War Department, we find it located in latitude 34° 18′ and in longitude 112° 40′ west of Greenwich, which last information is adopted for the present. Its elevation above the sea-level is 3,726 feet as determined by a boiling-point thermometer. The magnetic declination at this place I roughly estimate at 14° east, with perhaps an annual increase of 2′; the dip is probably near 60½°. The instrument was set up under a tent at 10 a. m., July 16, 4.4 feet above ground; geological formation, basaltic lava; no hills within three-fourths of a mile.

*Monthly means of hourly readings of the declinometer.*

[*Increasing* scale-numbers denote a movement of the north end of the needle towards the *east*.]

FORT STEILACOOM, W. T.

| | 0*h*. | 1*h*. | 2*h*. | 3*h*. | 4*h*. | 5*h*. | 6*h*. | 7*h*. | 8*h*. | 9*h*. | 10*h*. | 11*h*. | 12*h*. | 13*h*. | 14*h*. | 15*h*. | 16*h*. | 17*h*. | 18*h*. | 19*h*. | 20*h*. | 21*h*. | 22*h*. | 23*h*. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1866. | *Noon.* | | | | | | | | | | | | *Midn't* | | | | | | | | | | | |
| June | 21.32 | 21.16 | 21.11 | 21.14 | 21.19 | 21.33 | 21.41 | 21.50 | 21.47 | 21.51 | 21.53 | 21.49 | 21.51 | 21.56 | 21.58 | 21.59 | 21.70 | 21.78 | 21.92 | 21.99 | 22.05 | 21.97 | 21.79 | 21.54 |
| July | 21.06 | 20.93 | 20.85 | 20.93 | 21.00 | 21.11 | 21.18 | 21.23 | 21.22 | 21.25 | 21.26 | 21.22 | 21.28 | 21.27 | 21.31 | 21.32 | 21.49 | 21.70 | 21.74 | 21.83 | 21.88 | 21.70 | 21.46 | 21.29 |
| August | 20.99 | 20.92 | 20.85 | 20.95 | 21.09 | 21.18 | 21.19 | 21.26 | 21.27 | 21.33 | 21.29 | 21.24 | 21.26 | 21.28 | 21.30 | 21.33 | 21.44 | 21.58 | 21.76 | 21.82 | 21.79 | 21.57 | 21.31 | 21.14 |

CAMP DATE CREEK, ARIZONA.

| | 0*h*. | 1*h*. | 2*h*. | 3*h*. | 4*h*. | 5*h*. | 6*h*. | 7*h*. | 8*h*. | 9*h*. | 10*h*. | 11*h*. | 12*h*. | 13*h*. | 14*h*. | 15*h*. | 16*h*. | 17*h*. | 18*h*. | 19*h*. | 20*h*. | 21*h*. | 22*h*. | 23*h*. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1867. | | | | | | | | | | | | | | | | | | | | | | | | |
| Second half of July | 21.35 | 21.34 | 21.33 | 21.41 | 21.45 | 21.54 | 21.57 | 21.53 | 21.55 | 21.53 | 21.49 | 21.54 | 21.55 | 21.55 | 21.56 | 21.59 | 21.65 | 21.73 | 21.83 | 21.95 | 21.95 | 21.78 | 21.60 | 21.44 |
| August | 21.38 | 21.33 | 21.37 | 21.45 | 21.55 | 21.58 | 21.61 | 21.56 | 21.55 | 21.55 | 21.55 | 21.54 | 21.53 | 21.60 | 21.64 | 21.69 | 21.75 | 21.82 | 21.95 | 22.06 | 22.07 | 21.88 | 21.67 | 21.51 |
| September | 21.18 | 21.18 | 21.25 | 21.33 | 21.39 | 21.44 | 21.36 | 21.40 | 21.38 | 21.32 | 21.25 | 21.20 | 21.18 | 21.20 | 21.23 | 21.26 | 21.30 | 21.33 | 21.39 | 21.48 | 21.62 | 21.52 | 21.43 | 21.31 |
| October | 20.89 | 20.81 | 20.94 | 21.03 | 21.09 | 21.12 | 21.11 | 21.10 | 21.06 | 21.04 | 20.99 | 20.94 | 20.93 | 20.91 | 20.93 | 20.94 | 20.95 | 20.97 | 21.01 | 21.08 | 21.20 | 21.16 | 21.09 | 20.97 |
| November | 20.97 | 20.91 | 20.91 | 20.93 | 20.99 | 21.04 | 21.05 | 21.04 | 21.01 | 20.99 | 20.94 | 20.91 | 20.89 | 20.86 | 20.89 | 20.92 | 20.96 | 20.99 | 21.04 | 21.10 | 21.17 | 21.16 | 21.10 | 21.05 |

The monthly means are as follows: At Fort Steilacoom, June, 21.55, July, 21.31, and August, 21.30; at Camp Date Creek, July, 21.58, August, 21.63, September, 21.33, October, 21.01, and November, 20.99. These monthly means agree closely enough to make it unnecessary to correct the hourly readings for effect of any progressive change during one day. Subtracting each hourly mean from its respective monthly mean we obtain the following tables of the daily variation, a + sign indicating a position of the north end of the needle to the *west* of its monthly normal position.

*Daily variation in scale divisions.*

FORT STEILACOOM.

| | 0*h*. | 1*h*. | 2*h*. | 3*h*. | 4*h*. | 5*h*. | 6*h*. | 7*h*. | 8*h*. | 9*h*. | 10*h*. | 11*h*. | 12*h*. | 13*h*. | 14*h*. | 15*h*. | 16*h*. | 17*h*. | 18*h*. | 19*h*. | 20*h*. | 21*h*. | 22*h*. | 23*h*. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1866. | Noon. | | | | | | | | | | | | Midn't | | | | | | | | | | | |
| June | +0.23 | +0.39 | +0.44 | +0.41 | +0.36 | +0.22 | +0.14 | +0.05 | +0.08 | +0.04 | +0.02 | +0.06 | +0.04 | −0.01 | −0.03 | −0.04 | −0.15 | −0.23 | −0.37 | −0.44 | −0.50 | −0.42 | −0.24 | +0.01 |
| July | +0.25 | +0.38 | +0.46 | +0.38 | +0.31 | +0.20 | +0.13 | +0.08 | +0.09 | +0.06 | +0.05 | +0.09 | +0.03 | +0.04 | 0.00 | −0.01 | −0.18 | −0.39 | −0.43 | −0.52 | −0.57 | −0.39 | −0.15 | +0.09 |
| August | +0.31 | +0.38 | +0.45 | +0.35 | +0.21 | +0.12 | +0.11 | +0.04 | +0.03 | −0.03 | +0.01 | +0.06 | +0.04 | +0.02 | 0.00 | −0.03 | −0.14 | −0.28 | −0.46 | −0.52 | −0.49 | −0.27 | −0.01 | +0.16 |
| Mean | +0.26 | +0.38 | +0.45 | +0.38 | +0.29 | +0.18 | +0.13 | +0.06 | +0.07 | +0.02 | +0.03 | +0.07 | +0.04 | +0.02 | −0.01 | −0.03 | −0.16 | −0.30 | −0.42 | −0.49 | −0.52 | −0.36 | −0.13 | +0.09 |

CAMP DATE CREEK.

| | 0*h*. | 1*h*. | 2*h*. | 3*h*. | 4*h*. | 5*h*. | 6*h*. | 7*h*. | 8*h*. | 9*h*. | 10*h*. | 11*h*. | 12*h*. | 13*h*. | 14*h*. | 15*h*. | 16*h*. | 17*h*. | 18*h*. | 19*h*. | 20*h*. | 21*h*. | 22*h*. | 23*h*. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1867. | | | | | | | | | | | | | | | | | | | | | | | | |
| Half of July | +0.23 | +0.24 | +0.25 | +0.17 | +0.13 | +0.04 | +0.01 | +0.05 | +0.03 | +0.05 | +0.09 | +0.04 | +0.03 | +0.03 | +0.02 | −0.01 | −0.07 | −0.15 | −0.25 | −0.37 | −0.37 | −0.20 | −0.02 | +0.14 |
| August | +0.25 | +0.30 | +0.26 | +0.18 | +0.08 | +0.05 | +0.02 | +0.07 | +0.08 | +0.08 | +0.08 | +0.09 | +0.10 | +0.03 | −0.01 | −0.06 | −0.12 | −0.19 | −0.32 | −0.43 | −0.44 | −0.25 | −0.04 | +0.12 |
| September | +0.15 | +0.15 | +0.08 | 0.00 | −0.06 | −0.11 | −0.03 | −0.07 | −0.05 | +0.01 | +0.08 | +0.13 | +0.15 | +0.13 | +0.10 | +0.07 | +0.03 | 0.00 | −0.06 | −0.15 | −0.29 | −0.19 | −0.10 | +0.02 |
| October | +0.12 | +0.20 | +0.07 | −0.02 | −0.08 | −0.11 | −0.10 | −0.09 | −0.05 | −0.03 | +0.02 | +0.07 | +0.08 | +0.10 | +0.08 | +0.07 | +0.06 | +0.04 | 0.00 | −0.07 | −0.19 | −0.15 | −0.08 | +0.04 |
| November | +0.02 | +0.08 | +0.08 | +0.06 | 0.00 | −0.05 | −0.06 | −0.05 | −0.02 | 0.00 | +0.05 | +0.08 | +0.10 | +0.13 | +0.10 | +0.07 | +0.03 | 0.00 | −0.05 | −0.11 | −0.18 | −0.17 | −0.11 | −0.06 |
| Mean half July and Aug. | +0.24 | +0.27 | +0.25 | +0.18 | +0.11 | +0.04 | +0.02 | +0.06 | +0.06 | +0.07 | +0.08 | +0.07 | +0.06 | +0.03 | 0.00 | −0.03 | −0.10 | −0.17 | −0.29 | −0.40 | −0.40 | −0.23 | −0.03 | +0.13 |
| Mean, Sept., Oct., Nov. | +0.10 | +0.14 | +0.08 | +0.01 | −0.05 | −0.09 | −0.06 | −0.07 | −0.04 | −0.01 | +0.05 | +0.09 | +0.11 | +0.12 | +0.09 | +0.07 | +0.04 | +0.01 | −0.04 | −0.11 | −0.22 | −0.17 | −0.10 | 0.00 |

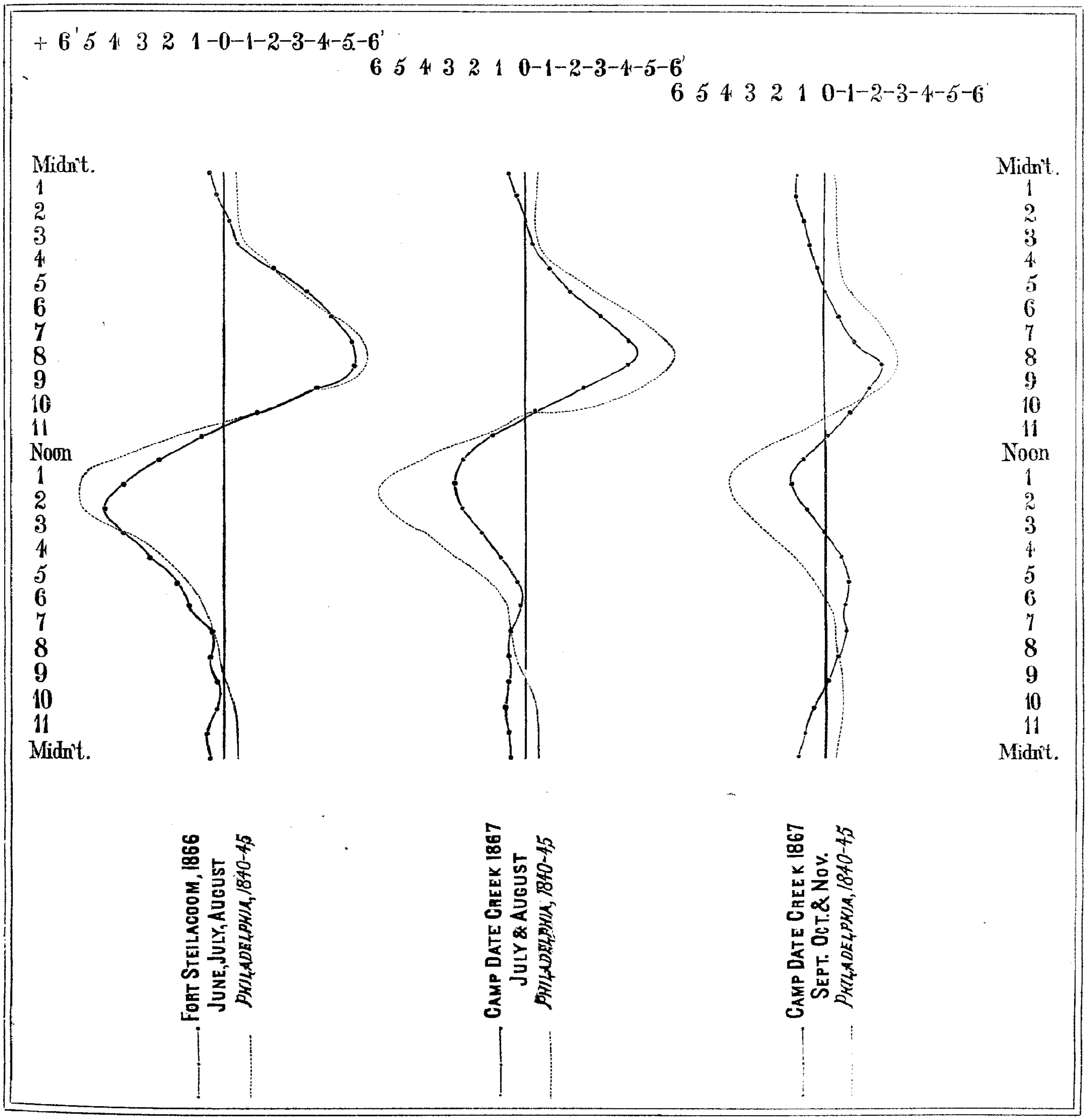
Converting scale divisions into minutes of arc, and adding, for comparison, values corresponding to the same months as found at Philadelphia during 1840–1845, (Coast Survey Report of 1860, pp. 306, 307,) we obtain the following table of the solar daily variation of the magnetic declination:

| Local time. | Fort Steilacoom, June, July, August, 1866. | Philadelphia, June, July, August 1840-1845. | Camp Date Creek, half of July, August, 1867. | Philadelphia, July, August, 1840-1845. | Camp Date Creek, September, October, November, 1867. | Philadelphia, September, October, November, 1840-1845. |
|---|---|---|---|---|---|---|
| *h.* | ′ | ′ | ′ | ′ | ′ | ′ |
| 0 (midnight) . | +0.4 | −0.5 | +0.6 | −0.7 | +1.1 | −0.4 |
| 1............. | +0.2 | −0.5 | +0.3 | −0.6 | +1.2 | −0.5 |
| 2............. | −0.1 | −0.4 | 0.0 | −0.4 | +0.9 | −0.5 |
| 3............. | −0.3 | −0.7 | −0.3 | −0.6 | +0.7 | −0.6 |
| 4............. | −1.6 | −1.4 | −1.0 | −1.5 | +0.4 | −0.7 |
| 5............. | −3.0 | −2.7 | −1.7 | −2.9 | +0.1 | −1.1 |
| 6............. | −4.2 | −4.2 | −2.9 | −4.4 | −0.4 | −2.0 |
| 7............. | −4.9 | −5.4 | −4.0 | −5.6 | −1.1 | −2.6 |
| 8............. | −5.2 | −5.3 | −4.0 | −5.5 | −2.2 | −2.8 |
| 9............. | −3.6 | −3.8 | −2.3 | −3.9 | −1.7 | −2.1 |
| 10............. | −1.3 | −1.1 | −0.3 | −1.0 | −1.0 | −0.3 |
| 11............. | +0.9 | +2.0 | +1.3 | +2.2 | 0.0 | +1.7 |
| 12 (noon)...... | +2.6 | +4.4 | +2.4 | +4.7 | +1.0 | +3.3 |
| 1............. | +3.8 | +5.5 | +2.7 | +5.8 | +1.4 | +3.8 |
| 2............. | +4.5 | +5.2 | +2.5 | +5.5 | +0.8 | +3.3 |
| 3............. | +3.8 | +4.0 | +1.8 | +4.1 | +0.1 | +2.3 |
| 4............. | +2.9 | +2.6 | +1.1 | +2.6 | −0.5 | +1.3 |
| 5............ | +1.8 | +1.5 | +0.4 | +1.4 | −0.9 | +0.5 |
| 6............. | +1.3 | +0.8 | +0.2 | +0.8 | −0.6 | 0.0 |
| 7............. | +0.6 | +0.5 | +0.6 | +0.6 | −0.7 | −0.3 |
| 8............. | +0.7 | +0.2 | +0.6 | +0.3 | −0.4 | −0.5 |
| 9............. | +0.2 | 0.0 | +0.7 | 0.0 | −0.1 | −0.7 |
| 10............. | +0.3 | −0.3 | +0.8 | −0.4 | +0.5 | −0.7 |
| 11............. | +0.7 | −0.5 | +0.7 | −0.6 | +0.9 | −0.5 |
| 12 (midnight) . | +0.4 | −0.5 | +0.6 | −0.7 | +1.1 | −0.4 |

The above tabular results are exhibited graphically on the annexed diagrams.

Considering that the Fort Steilacoom and Camp Date Creek values embrace but part of a single cycle, whereas the Philadelphia values are means depending on a number of years of observations, and considering that the epochs do not nearly correspond to the same phase in the eleven-year cycle, during which the daily amplitude undergoes its changes of magnitude, the general correspondence in the daily movement and in the annual variation of the daily movement is sufficiently conspicuous. Supposing in the diagram the north end of the needle to point upwards when in its normal direction, its easterly deflections are shown to the right, and its westerly deflections to the left of the medial vertical line. The total variation at Fort Steilacoom (horizontal force about 4.2) is nearly the same as at Philadelphia, (horizontal force 4.17,) but at Camp Date Creek (horizontal force about 5.9) it is very much less, and not in the inverse proportion of the horizontal forces at the two stations. At Fort Steilacoom, during the summer months, the eastern elongation took place at 8 a. m., (at Philadelphia at 7½ a. m.,) and the western elongation at 2 p. m., (at Philadelphia at 1¼ p. m.;) the times of the daily extremes appear therefore somewhat delayed at Steilacoom. A secondary westerly movement between 9½ and 11 p. m. is almost masked by accidental irregularities. At Camp Date Creek the eastern elongation is reached at 7¾ a. m. in July and August, and a little before 8 a. m. in the autumn months, (about the same as at Philadelphia,) and the western elongation shortly before 1 p. m., (about the same time at Philadelphia;) the secondary movement is more decided than at Fort Steilacoom, and seems to commence soon after sunset, attaining its westerly maximum about 10 p. m. and 1 a. m.; in summer and autumn, respectively, it forms part of the annual variation, and appears also in the Philadelphia curves of the daily variation.

It will be observed that the mean of the readings of the principal elongations of the daily variation will not represent the average direction for the day, (lacking a correction of less than 1′,) owing to the fact of the eastern extremes being much more strongly developed than the western.


+ 6 5 4 3 2 1 -0-1-2-3-4-5-6
6 5 4 3 2 1 0-1-2-3-4-5-6
6 5 4 3 2 1 0-1-2-3-4-5-6
Midn't.
1
2
3
4
5
6
7
8
9
10
11
Noon
1
2
3
4
5
6
7
8
9
10
11
Midn't.
Fort Steilacoom, 1866
June, July, August
Philadelphia, 1840-45
Camp Date Creek 1867
July & August
Philadelphia, 1840-45
Camp Date Creek 1867
Sept. Oct. & Nov.
Philadelphia, 1840-45

# APPENDIX No. 16.

## REPORTS OF OBSERVATIONS UPON THE TOTAL SOLAR ECLIPSE OF DECEMBER 22, 1870.

(December 21, Washington astronomical time.)

COAST SURVEY OFFICE, *May* 1, 1871.

DEAR SIR: Having been appointed a member of your party for observing, in Sicily, the eclipse of the sun of December 22, 1870, I joined you at New York, on board the steamer Algeria, October 13. The special duty assigned me, besides the direct observations of the eclipse, was the determination of the geographical position of the central station occupied by the Sicilian party. For this purpose I provided myself with a meridian telescope, (as described in Appendix No. 8, Coast Survey Report of 1867,) to be used for finding the time and latitude, also for observing the eclipse; I had also a small theodolite for local triangulation, a hand-telescope, and a sidereal chronometer, rated at Washington; this box-chronometer I carried by hand, going and returning, not trusting it to the care of any one. The instruments, together with a number of cases containing the spectroscopic outfit of the English party, under the direction of Mr. J. N. Lockyer, were shipped from Liverpool direct to Messina, care of our consul, Mr. F. W. Behn. Special arrangement had been made to insure their safe transportation, and they reached their destination in good condition.

On the way from London to Florence frequent chronometer comparisons were made, with a view of testing the performance of your two pocket-chronometers. At Munich I assisted in the purchase of some hand-telescopes and other small instruments. By the courtesy of the directors of the respective observatories, I was able to obtain comparisons of my sidereal chronometer with the clocks at the observatories at Berlin, Munich, and Naples. On my return from Sicily I again compared the chronometer with the Naples clock.

For the purpose of selecting a suitable locality for our observations of the eclipse at Catania, I left you at Florence, November 29, and arrived at Catania December 5. With the assistance of the consul, the instruments arrived from Messina, by rail, the same day. On the following day no suitable locality was found, but on the 7th, with the assistance of our vice-consul at Catania, Mr. A. Peratoner, and at the suggestion of Professor Orazio Silvestri, the garden of the Benedictine monastery of Sta. Nicola, situated in the western part of the city, was found to be a most desirable location, and was accordingly selected for our station. Upon the arrival of the photographic instruments and outfit of our party, on the 11th, I mounted the transit, on the following day, in the southeastern corner of the garden, by the side of the photographic tent. Subsequently the English observers, under Mr. Lockyer, located themselves in the western portion of the garden. On the 7th Dr. C. H. F. Peters arrived, and on the 9th I visited with him Carlentini, south of Catania, and nearer to the central line of the shadow. The station was afterward occupied by Professor J. C. Watson.

The meridian instrument was mounted on its packing-box, which had been filled with blocks of lava, the weight of which was sufficient to render it sufficiently steady. At the close of each night's observation, the telescope was dismounted, but the frame was left standing, covered with a piece of oil-cloth, to protect it against rain and dust. A meridian-mark was put up, and a small geodetic survey was made to connect the station with the triangulation of this part of Sicily, executed about thirty years ago, by Dr. Peters. The position of the station is referred to the center of the dome of the church of Saint Nicholas. The elevation of the ground of the garden above the sea-level was found to be nearly 40 meters, by repeated measures with an aneroid barometer, the scale of which had been tested.

The results for local time, from observations* with the meridian telescope No. 9, are as follows:

Correction ($\Delta T$) to sidereal chronometer, Kessel, 1287.

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* In recording most of these observations, as well as those for latitude, I was assisted by Mr. W. Eimbeck, who arrived on the 15th.

| Date. | Sidereal hour. | Δ T, Catania sidereal time. | Daily rate. |
|---|---|---|---|
| 1870. | | h. m. s. | s. |
| Dec. 13 | 0.0 | +6 07 46.44 | −0.53 |
| 15 | 1.7 | 45.35 | −0.99 |
| 19 | 23.7 | 41.44 | −0.42 |
| 20 | 1.7 | 40.98 | −0.85 |
| 22 | 22.8 | 39.28 | |

By comparisons with Kessel 1287 other chronometers were rated as follows:

*Corrections and rate of mean time chronometer Hornby 1107, used for timing the photographic plates at Catania.*

| Date. | Hour. | Correction Δ T, Catania mean time. | Difference. |
|---|---|---|---|
| 1870. | h. m. | s. | s. |
| Dec. 13 | 2.30 p.m. | +51.2 | −3.4 |
| 14 | 0.45 | 47.8 | −3.8 |
| 15 | 1.45 | 44.0 | −4.0 |
| 16 | 2.00 | 40.0 | −3.2 |
| 17 | 2.30 | 36.8 | −2.1 |
| 18 | 0.45 | 34.7 | −4.1 |
| 19 | 0.15 | 30.6 | −3.7 |
| 20 | 11.45 a.m. | 26.9 | −4.5 |
| 21 | 0.30 p.m. | 22.4 | −3.8 |
| 22 | 10.30 a.m. | 18.6 | −4.4 |
| 23 | 2.30 p.m. | +14.2 | |

*Correction and rate of sidereal time chronometer Hutton 208, used by Dr. Peters at the western peak of the Monte Rosso.*

| Date. | Hour. | Correction Δ T, Catania sidereal time. | Difference. |
|---|---|---|---|
| 1870. | h. m. | s. | s. |
| Dec. 13 | 20 | +10.3 | −2.9 |
| 14 | 18 | + 7.4 | −2.9 |
| 15 | 19.30 | + 4.5 | −4.5 |
| 16 | 19.30 | 0.0 | −3.3 |
| 17 | 20.15 | − 3.3 | −2.0 |
| 18 | 18.30 | − 5.3 | −3.7 |
| 19 | 18.15 | − 9.0 | −3.5 |
| 20 | 17.45 | −12.5 | |
| 21, 22 | Taken to Monte Rosso.—W. P.* | | |
| 23 | 20.30 | −53.6 | |

These two box-chronometers were received at Catania, December 13.

* On the morning of the day of the eclipse, heliotrope signals were exchanged between Dr. Peters's and Mr. Eimbeck's station at Monte Rosso and my station in the garden at Catania, from which I deduce, Δ T (Catania sidereal time) December 22, at $16^h$ sidereal time $= -39^s.2$; hourly rate $-0^s.15$.

The correction and rate of your mean-time pocket-chronometer, "Parkinson and Frodsham 5389," on Catania mean time, was found as follows:

1870. December 15, $\Delta T = +5^h\ 44^m\ 26^s.3$
December 21, $27\ .5$  $\delta T = +0^s.2$.

This chronometer was taken to Syracuse, between the 15th and 21st, for the purpose of comparison with the time determined by the United States Naval Observatory party.

The correction and rate of your mean-time pocket-chronometer, "Frodsham 04211," on Catania mean time, was found as follows:

1870. December 15, $\Delta T = +0^h\ 59^m\ 18^s.2$
19, $11\ .1$  $\delta T = -1^s.8$
20, $08\ .6$  $-2\ .5$
21, $03\ .1$  $-5\ .5$

[N. B.—Since its arrival at Catania, this chronometer assumed a rapidly changing rate.]

The correction to mean-time pocket-chronometer, "French Royal Exchange, London, 4136," belonging to Mr. Lockyer, was found as follows:

December 21, noon, slow of Catania mean time $1^s.3$. (Rate not known.)

The correction to Professor Watson's mean-time pocket-chronometer, (used at Carlentini,) was found as follows:

December 21, $6^h\ 32^m\ 39^s.8$ }
December 23, $6\ \ 32\ \ 37\ .0$ } Slow of Catania mean time.

For the latitude of the station, I find the following individual results from observations with meridian telescope No. 9, on December 16, 17, 19, and 20.

| Pairs of stars B. A. catalogue. | | Number of observations. | Latitude. |
|---|---|---|---|
| | | | ° ′ ″ |
| 8206 and | 8245 | 1 | 37 30 08. 3 |
| 8289 | 8324 | 2 | 08. 2 |
| 8344 | 26 | 1 | 12. 2 |
| 8366 | 26 | 2 | 09. 2 |
| 79 | 178 | 4 | 10. 7 |
| 222 | 327 | 3 | 12. 4 |
| 416 | 500 | 2 | 08. 3 |
| 540 | 569 | 2 | 09. 9 |
| 684 | 744 | 3 | 08. 9 |
| 827 | 872 | 3 | 10. 1 |
| 904 | 1006 | 3 | 11. 7 |
| 1057 | 1127 | 1 | 07. 8 |
| 1257 | 1293 | 1 | 10. 8 |

Resulting, latitude $37^\circ\ 30'\ 09''.9 \pm 0''.3$. Reduction to center of dome of church of Saint Nicholas, by triangulation, $+3''.5$. Resulting latitude of dome, $37^\circ\ 30'\ 13''.4$.*

The longitude was determined by means of chronometers as follows:

1. By sidereal chronometer, Kessel, 1287, compared with the Naples clock;

| | |
|---|---|
| Naples, December 2....... $\Delta T = +6^h\ 04^m\ 19^s.8$ | Catania, December 13..... $\Delta T = +6^h\ 07^m\ 46^s.4$ |
| Naples, December 31...... $+6\ \ 04\ \ 24\ .1$ | Catania, December 23..... $+6\ \ 07\ \ 38.\ 5$ |

Hence daily *traveling* rate $+0^s.64$.

And difference of longitude, $\Delta\lambda$....... $-3^m\ 19^s.5$

Longitude of observatory Capo di Monte $-6^h\ 05\ \ 11\ .0$

Longitude of Catania.................. $-6\ \ 08\ \ 30\ .5$ from Washington.

* An inscription on the pavement of the church, dated January, 1841, states the latitude $37^\circ\ 30'\ 15''.5$, as determined by Sartorius of Waltershausen and Dr. Peters; the latter corrected it afterward to $37^\circ\ 30'\ 12''.8 \pm 0''.5$ (See Atti dell' Academia Gioenia di scienze naturaly di Catania, serie seconda, tomo IV, Catania, 1847.)

2. By mean-time pocket-chronometer, "Parkinson and Frodsham, 5389," compared with the Munichclock:

Munich, November 21, $\Delta T = + 5^h\ 30^m\ 28^s.6$
Catania, December 15, $+ 5\ \ 44\ \ 26\ .3$

The daily traveling rate of this chronometer, between Boston and Greenwich, was — $0.^s15$; between Berlin and Munich — $0^s.03$, and at Catania (stationary) + $0^s.20$; the rate between Munich and Catania was taken 0.00; hence:

| | h. | m. | s. |
|---|---|---|---|
| Difference of longitude $\Delta\lambda$ | — 0 | 13 | 57.7 |
| Longitude of Observatory of Munich (Bogenhausen) | — 5 | 54 | 38.0 |
| Longitude of Catania | — 6 | 08 | 35.7 |

3. By mean-time pocket-chronometer, Frodsham 04211, also compared at Munich:

| | h. | m. | s. | |
|---|---|---|---|---|
| Munich, November 21 .... $\Delta T =$ | + 0 | 45 | 41.6 | Average daily rate, during 17 days, between London and Munich, —$0^s.86$. |
| Rate for 24 days | | | —20.6 | |
| $\Delta T$ December 15 | 0 | 45 | 21.0 | |
| $\Delta T$ December 15, Catania | + 0 | 59 | 18.2 | |
| Difference of longitude $\Delta\lambda$ | — 0 | 13 | 57.2 | |
| Longitude of observatory, Munich | — 5 | 54 | 38.0 | |
| Longitude of Catania | — 6 | 08 | 35.2 | |

4. By exchange of chronometer times with the United States Naval Observatory party at Syracuse. Chronometer Negus 1228* was compared with pocket-chronometer Parkinson and Frodsham, 5389, carried to Syracuse by Mr. H. Peirce.

| | h. | m. | s. |
|---|---|---|---|
| December 19. Negus, 1228, at comparison | 0 | 37 | 00.0 |
| Correction | | | —36.0 |
| Greenwich, mean time of comparison | 0 | 36 | 24.0 |
| Parkinson and Frodsham, 5389 | 7 | 54 | 18.4 |
| Parkinson and Frodsham, slow of Greenwich mean time | 4 | 44 | 05.6 |
| Parkinson and Frodsham, slow of Catania mean time | 5 | 44 | 27.1 |
| Catania, east of Greenwich | 1 | 00 | 21.5 |
| Difference of longitude, Greenwich and Washington | 5 | 08 | 12.0 |
| Longitude of Catania | —6 | 08 | 33.5 |

*Recapitulation of results for longitude of Catania.*†

| | h. | m. | s. | |
|---|---|---|---|---|
| 1. By Kessel, 1287, (Naples) | — 6 | 8 | 30.5 | Weight, 3 |
| 2. By Parkinson and Frodsham, 5389, (Munich) | — 6 | 8 | 35.7 | 1 |
| 3. By Frodsham, 04211, (Munich) | — 6 | 8 | 35.2 | 1 |
| 4. By Negus, 1228, (Syracuse) | — 6 | 8 | 33.5 | 1 |
| Weighted mean | — 6 | 8 | 32.6 | |
| Geodetic reduction to center of dome | | | + 0.4 | |
| Longitude center of dome church of St. Nicholas | — 6 | 8 | 33.0 from Washington.‡ | |
| | [— 1 | 0 | 21.0 from Greenwich.] | |

* The correction on Greenwich time for this chronometer, at the time of comparison, I obtained from Professor Hall, United States Navy. The chronometer came by sea, via Malta.

† By Professor Watson's pocket-chronometer, compared at Ann Arbor, Michigan, and at Catania, the longitude of Catania was found to be — $6^h\ 08^m\ 47^s.1$, but as the time elapsed was considerable, I did not think it safe to trust to the uniformity of the rate, and consequently no use was made of this result.

‡ The inscription on the floor of the church (as mentioned before) makes Catania $51^m\ 4^s$ east of Paris, (or in longitude — $6^h\ 08^m\ 36^s.5$,) and as corrected afterwards by Dr. Peters, $6^m\ 43^s$ east of Berlin, (or in longitude — $6^h\ 08^m\ 30^s.3$.)

By means of a small triangulation, a base measure, and the azimuth of the mark, the following geographical positions were determined. To these I have added Monte Rosso station and your station, "Villa del Marchese di San Giuliano," near Catania, derived from Dr. Peters's difference of latitude and longitude with the Church of St. Nicholas. The approximate altitude of the villa is 207 meters.*

| Geographical positions. | Latitude. | Longitude east of Washington. |
|---|---|---|
| | ° ′ ″ | h. m. s. |
| Catania: meridian telescope and equatorial of photographers in southeast corner of garden of Benedictine Monastery. | 37 30 09.9 | 6 8 32.6 |
| Catania: dome of monastery of Sta. Nicola, center | 37 30 13.4 | 6 8 33.0 |
| Catania: station in garden, English equatorial | 37 30 11.2 | 6 8 32.4 |
| Catania: station in garden, Mr. Lockyer's, spectroscope | 37 30 10.4 | 6 8 32.4 |
| Catania: pavilion in northwest corner of garden, Mr. Lane's, and English photometric station | 37 30 12.6 | 6 8 32.4 |
| Monte Rosso: western peak, monument | 37 37 07.8 | 6 8 16.4 |
| Villa of the Marchese di San Giuliano, north of Catania | 37 32 29.2 | 6 8 32.7 |

By means of Agnello's† map, I obtain for the position of Professor Watson's station at Carlentini, approximately, latitude 37° 16′ 16″, longitude $6^h$ $8^m$ $13^s.7$ (east).

A daily record of the weather was kept while in Sicily; it was fair enough until the day preceding the eclipse, when a change occurred, bringing on clouds and occasional rain. Early in the day, December 22, the sky, to a great extent, was clear, but as the morning advanced clouds appeared from the northward and westward, which unfortunately, during the time of the eclipse, became so dense as almost to hide the whole phenomenon from our view. Beyond noting the time of the first contact, and recording the impression of a momentary glimpse of a portion of the corona through a rent in the clouds, little more could be done. The phenomena of the two inner contacts, and of the last contact, were not observable, on account of the presence of the dark-blue clouds. Some rain fell for a short time.

A little before the predicted time of beginning, Mr. Lockyer caused a pistol to be discharged, noted by me at $12^h$ $32^m$ $11^s.0$, by Kessel 1287, and about $1\frac{3}{4}$ seconds later a second shot was heard, intended, I believe, to indicate the time of the first observed spectroscopic contact of the moon's limb with the outer chromosphere. At this time and until $12^h$ $32^m$ $25^s$ I could see no change in the sun's outline at the place where the first contact was expected, the limb being very irregular and wavy. About $12^h$ $32^m$ $25^s$ I supposed the moon had advanced upon the sun, but waited till $12^h$ $32^m$ $29^s.5$, when it was evident the moon had made a perceptible indentation; I then pulled the string connected with the photographic equatorial and exposed the first plate of the eclipse. At $12^h$ $55^m$ $26^s.5$, the moon came in contact with the umbra of the first large spot, and at $13^h$ $01^m$ $01^s.5$ with that of the second spot. At $13^h$ $30^m$ heavy clouds passed rapidly over the sun, and at $13^h$ $50^m$ drops of rain fell. At $13^h$ $55^m$ $55^s$ the sun was again obscured, but at $13^h$ $57^m$ $55^s$ a rent in the cloud revealed the eastern and northern part of the corona (about 120° of the lunar circumference) for about 3 seconds. This part of the corona had a sharp outline, nearly concentric with the moon, except on the northeast, where it extended to a greater distance; its average width was estimated at one-third of the moon's radius. There was no gradual shading off and no long rays as was noticed at Springfield, Illinois, during the total eclipse of August 7, 1869. The color was of the same silvery white. No protuberances were seen with the naked eye. The color of the sky near the southern and eastern horizon ‡ was of a light orange-yellow, considerably brighter than the yellow tint as seen at Springfield; the clouds overhead were of a deep indigo blue, with purple shades; altogether the darkness was much less than that witnessed at Springfield, so that at first I could

* According to Dr. Peters.

† Sull' Ecclisse totale di sole del 22 Dicembre, 1870, visibile in Sicilia, &c., &c., da Angelo Agnello, Palermo, 1870.

‡ Other parts obstructed by trees and buildings.

hardly persuade myself that totality had set in.* A bright star in the southeast was noticed by bystanders. At $13^h\ 59^m\ 5^s$ it grew lighter, but the totality must have ended some seconds before this, as the sun was at the time thickly covered by clouds. Cleared again partially at $14^h\ 30^m$, clouded up at $15^h\ 5^m$, and remained so until after the end of the eclipse. During the progress of the eclipse no regularity in the timing of the photographs could be preserved, as they had to be taken during the temporary clear intervals. The correction of the chronometer, Kessel, 1287, is $+\ 6^h\ 7^m\ 39^s.4$ to Catania sidereal time.

The first contact of the eclipse, therefore, was observed at the Catania station at $18^h\ 40^m\ 04^s.4$ Catania sidereal time, or $3^s.9$ later than the time predicted by the data of the American ephemeris.†

The computed times I obtained as follows:

| | h. m. s. | | | h. m. s. | | |
|---|---|---|---|---|---|---|
| Beginning of eclipse | 0 36 42.8 | Catania M. T., | or | 18 40 00.5 | Catania S. T. | |
| Beginning of totality | 2 01 23.0 | " | " | 20 04 54.6 | " | " |
| Ending of totality | 2 03 01.8 | " | " | 20 06 33.7 | " | " |
| Ending of eclipse | 3 20 27.2 | " | " | 21 24 11.8 | " | " |
| Duration of eclipse | 2 43 44.4 | M. T. | | 2 44 11.3 | S. T. | |
| Duration of totality | 1 38.8 | " | | 1 39.1 | " | |

A few transits of stars for time were observed before darkness set in. The instruments were taken to Messina, and left in charge of our consul, Mr. Behn, to be shipped to New York. We reached Boston in the steamer Tripoli, February 2, 1871, and on the 4th I reported for duty at the office here. The instruments arrived in New York in the steamer Anglia, on the 24th of February.

The records, original and duplicate, and the computations connected with the eclipse, are deposited in the archives of the office.

I remain, sir, yours, very respectfully,

CHARLES A. SCHOTT,
*Assistant United States Coast Survey.*

Professor BENJAMIN PEIRCE,
*Superintendent United States Coast Survey,*
*And in charge of the United States Eclipse Expedition to Europe.*

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SIR: Having been invited by you to join in the United States expedition for observing the late eclipse, I sailed from New York in October last, in company with yourself and some other members of the party.

During the passage to Liverpool, reflection upon the shortness of the period of totality led me to reconsider the views I first proposed as to the plan of observation, and with your approval I concluded to undertake spectroscopic observations of the corona. I arrived in London on the evening of the 26th of October, and soon after I was placed by you in communication with Mr. J.

* A pistol was fired off at $13^h\ 57^m\ 11^s.5$, the *estimated* time of commencement of totality. The phenomenon itself was hidden by clouds.

† The predicted times for Catania, by Agnello, (see his pamphlet,) are as follows:

| | | | | |
|---|---|---|---|---|
| First outer contact | $0^h$ | $38^m$ | $18^s.6$ | Catania mean time. |
| First inner contact | 2 | 01 | 01 .1 | |
| Second inner contact | 2 | 02 | 38 .5 | |
| Last outer contact | 3 | 20 | 19 .5 | |
| Duration of eclipse | 2 | 42 | 0 .9 | |
| Duration of totality | | 1 | 37 .4 | |

$\phi = 37^\circ\ 30'\ 2''.1$; $\lambda = 3^m\ 19^s.8$ east of Naples, for Piazza del Duomo, which is east and south of the Coast Survey station.

His assumed geographical position differs but little from mine, and does not account for the defect in the predicted time of beginning, which is over 1½ minutes too late. Similar differences exist for *Augusto* $\phi = 37^\circ\ 13'\ 48''$; $\lambda = -\ 1^h\ 00^m\ 52^s.1$ from Greenwich. Beginning by American ephemeris data $0^h\ 37^m\ 38^s$; first inner contact, $2^h\ 02^m\ 18^s$; second, $2^h\ 04^m\ 06^s$; end, $3^h\ 21^m\ 26^s$, Augusto mean time. Agnello gives $0^h\ 39^m\ 17^s$, $2^h\ 1^m\ 57^s$, $2^h\ 3^m\ 47^s.5$, and $3^h\ 21^m\ 21^s$, respectively. Using the data of the English Nautical Almanac, the predicted times for *Catania* become $0^h\ 36^m\ 22^s$ and $3^h\ 20^m\ 08^s$ Catania mean time, for first and last contacts respectively.

Norman Lockyer, so distinguished for his spectroscopic discoveries in the sun. I wish here to express my obligations to him for his suggestions and attentions. I was by him introduced to the eminent optician, Mr. John Browning, of London. After consultation with the latter upon what I wanted, he engaged to make for me one of his direct vision sun spectroscopes. The construction of this and of all the other instrumental appliances for the occasion was at my own cost.

My aim was primarily to have the spectroscope so mounted upon, or in connection with, an equatorial moved by clock-work, that it could be revolved with ready freedom around the center of the sun's image, as a center of revolution, the slit of the spectroscope always spanning the coronal ring radially from the sun's limb outward, and of course sweeping the entire ring. This aim was, in great measure, already anticipated in Mr. Browning's arrangement. The only modification by myself in this respect was designed merely for greater security, both of the precision and of the perfect freedom, of the motion of revolution of the spectroscope system.

In case there should appear one or more condensed masses of white light, similar to the two noticed by myself in the eclipse of 1869, it was not improbable that such a condensation might be marked by a local comparative brilliancy in the bright line in the spectrum of the corona. And with sufficient power in the spectroscope, it was also a possible contingency, especially if such bright line coincide with a dark line in the skylight solar spectrum, that such local brilliancy of the line might be visible some minutes before and after the total phase, in the same way that Messrs. Lockyer and Janssen brought out the red hydrogen line in the absence of all eclipse. This might altogether give a considerable period of time, and it was thought desirable to provide a means for recording with approximate exactness the position of any such condensation of light at three several recorded times, in case it should appear in the spectrum some minutes before totality. And if this should be otherwise, I still very much desired to locate with some precision what should be seen in the total phase. These views I state now, partly by way of apology for having run the risk of failure by undertaking more than could be accomplished with ease and certainty in the time at my disposal. The consequence was that several untoward circumstances and unexpected accidents prevented the completion of the arrangements, so that when the eclipse came they were in large part not ready for use.

The parts brought actually into use for service on the eclipse consisted of the sun spectroscope, made for me by Mr. Browning, as above mentioned, of the Coast Survey 4-inch Dollond telescope, of 6 feet focal distance, and of a temporary equatorial mounting, on which both these were supported. This equatorial mounting was specially arranged for the circumstances of the eclipse in Sicily, and gave a direct rigid support in declination to the object-glass of the telescope. The stellar focus of the object-glass fell within two or three inches of the northern cylindrical bronze pivot of the equatorial axis, and upon this pivot was directly supported the chief one of the pair of bronze bearings, fixed in the telescope-tube, on which the spectroscope system could be freely revolved. This special and temporary arrangement was resorted to with the view of insuring the telescope against shake in manipulating the spectroscope, and this purpose it served effectually.

The angle of aperture of the collimator of the spectroscope was much larger than that of our 4-inch Dollond of 6 feet focus, having been first intended for a different telescope. In order, therefore, to enlarge this small angle of aperture of the telescope and make it fill that of the collimator of the spectroscope, there was mounted in the spectroscope system, so as to revolve with it, a combination of a small plano-convex lens of 1¼ inches focal distance, with a small plano-concave lens of one-half inch focal distance, placed at a distance from the plano-convex equal to the difference of their focal distances. The pencils from the object-glass, traversing first the plano-convex and then the plano-concave, came to their foci at the slit of the spectroscope at something over one eighth of an inch beyond the plano concave. In this way such of the telescopic pencils as traversed this combination, embracing a field of over 13 minutes in diameter, arrived at the slit of the spectroscope as if they had come from a 4-inch object-glass of 32 inches focal distance. Of course the introduction of these lenses was in itself objectionable, but for the occasion there was no other choice, since the gain in intensity of light by enlargement of the angle of pencil, and reduction to four-ninths in the linear extent of the telescopic image, was much greater than the loss by reflection of the four additional surfaces.

In view of the shortness of the time, I left the spectroscope entirely to Mr. Browning, the maker, confining myself to the arrangement of some of its accessories. The instrument proves to be one of the first order of excellence, but I will remark that it is not as large and powerful an instrument as I had in mind in designing my plans of observation. It contains two bundles of prisms, each bundle consisting of three prisms of Chance's heavy flint-glass, and four reverse prisms of crown-glass, all cemented together. The angle of dispersion of a like bundle tried at Mr. Browning's was found to be not far from midway between the angle of dispersion of one and that of two prisms of common flint-glass of 60°. The angle of dispersion of the two bundles is, therefore, supposed to be about equal to that of three prisms of common flint-glass of 60°. The breadth of the transmitted pencil of rays of any one refrangibility in nearly the whole of the visible spectrum, is, in the air, about four-tenths of an inch along the plane of dispersion, so that in analyzing power the two bundles together represent a common flint-glass prism of 60°, measuring 2 inches on its sides. As the Huygenian eye-piece furnished with the little telescope of the spectroscope was of somewhat low power, I had an extra Ramsden eye-piece of greater power provided, and have used it exclusively. With this the little telescope gives a power of about 9, being a little over 20 for one inch in effective width of aperture. The little telescope is mounted on pivots, so as to sweep the length of the spectrum.

Anxious to have the means of trying the effect of multiplying the dispersion of the instrument, I devised, and had made, an artifice by which the light could be passed three times through the two bundles of prisms. This would involve a reduction of one-half in the quantity of light by division of the pencil, and a further reduction from loss by reflections and absorption. In these losses the light of the continuous spectrum would share in common with any monochromatic light; besides this, the continuous spectrum would suffer from the trebled dispersion a threefold reduction of intensity, in which the bright line of the monochromatic light would not share. Whether the result would favor the eye in analyzing the latter from the former, would obviously depend on the sufficiency or insufficiency of the original intensity of the latter. There was not time before the eclipse to perfect the adjustment of this contrivance and remedy a defect which existed in it. It was, therefore, thrown out entirely, but it may be as well to describe it. It will recall the methods by which the English philosophers and our own Professor Young have made the light pass twice through the prisms. But in the element by which the light is passed through the third time, it is, I think, new, and though objectionable in placing glass surfaces very near a focal image, may yet receive other applications which I purpose to communicate on another occasion. For ease of verbal description, imagine the spectroscope to be placed with the line of collimation of its collimator, horizontal, and its plane of dispersion, or plane of sweep of its telescope, vertical, and, of course, the slit of the collimator horizontal. The whole half of the slit on the one side of the axis or line of collimation of the collimator is to be closed. The slit, for the remaining half of its length on the other side of the axis, is left open for the admission of light as usual. A pencil of rays of any one refrangibility, issuing from any one point in this line of light, will pass through the prisms as parallel rays and continue on in the usual manner until they arrive at the object-glass of the little telescope. But before the pencil enters the object-glass one-half of it meets a semicircular plane-reflector, attached to the end of the telescope, so as to cover one of the halves into which the object-glass is divided by a vertical diameter. And the plane of this reflector is normal to the axis or line of collimation of the little telescope. The other half of the pencil, going through the uncovered half of the object-glass, reaches the eye of the observer, who sees, deprived of half its light, the usual spectrum vertically spanning, say the right-hand half of his field of view. As the vertical width of the half pencil is undiminished, the increase of diffraction, it is supposed, will take place solely along the lines of the spectrum, and not at all across them. The same remark applies to the reflected half of the pencil, whose course it remains to trace. The little telescope can be moved in its vertical sweep until its axis and the normal of the plane-reflector have the same inclination to the horizon as the pencil of the one refrangibility, and this last has to them only its small inclination in azimuth. The consequence is that it is returned through the prisms and collimator in such a manner that all the pencils of the same refrangibility would form upon the closed half of the slit a reflected image of its open half, and extending above and below would be a doublymagnified image of the neighboring parts of the spectrum. But just before the reflected half pencils come to their several foci in the reflected double spectrum, they encounter, first the convex surface, and next the plane surface, of a plano-convex lens, whose stellar focal length is roughly equal to that of the collimator itself. The part of the lens before the open half of the slit should be cut away, to prevent the reflection and scattering there of a portion of the intense light of the slit. At the plane surface of the lens the half pencil enters, cemented to that surface, a right-angled reflecting glass prism. The right-angled edge of the prism, opposite to the side by which it is cemented to the lens, is set back between the jaws of the slit until it lies nearly coincident with the closed half of the slit itself. The lens causes any ray which comes from the center of the collimator object-glass to return to that center after its two reflections from the prism, and the half pencils which come from one side the vertical diameter of the object-glass are reversed horizontally and thrown to the other side on their return, and so, making a third transit through the prism, they pass through the open half of the object-glass of the little telescope, and the observer sees a trebly-magnified spectrum vertically spanning the left-hand side of his field of view as the primary one does the right.

It is to be remarked that the vertical spectrum which would be formed by the half pencils arriving at the right-angled prism is inverted, in consequence of the two reflections from that prism, and this is essential, since otherwise the third dispersion would be subtracted from the first two instead of being added.

For the equatorial motion an extemporized clock-work was devised, on a plan admitting of ready and easy construction, with due regard to precision, and a mechanic in London was employed to make it, under an engagement to have it ready by the 20th of November. When I came to leave for Sicily, in the beginning of December, part of this work was still not done, and part of the remainder required doing over. In consequence I had to take it with me incomplete, in addition to a supply of tools, with the hope that I might find time to finish it myself, at my station. But to my great vexation, on the day of the eclipse the clock-work failed to come into use, for the want of only a few hours more of time, and my only resource was an assistant to shift the instrument little by little in right ascension. For this service I had to rely on my interpreter, who, though unpracticed, soon learned to perform the duty in a manner more satisfactory than might have been expected.

The regulator for the clock-work was a pendulum suspended by a small steel wire several feet in length, so as to admit of motion in a circular orbit, maintained by a radius-bar at the end of the clock-train, in the manner now well known. Airy was, I think, the first to apply the pendulum in this way for this purpose. At the beginning of the clock-train was placed a brass windlass, some 1¾ inches in diameter, to be driven by a very small iron wire, acted on in its turn by a circular arc of wood, attached to the equatorial in such manner as to be almost connected with the object-glass of the large telescope. Into the clock-train entered also a brass wheel of some 7 inches in diameter, acting, by a second fine iron wire, upon a second brass windlass, one purpose of this being to mitigate the effect of inaccuracy in gear-teeth.

Had there been time, it was in contemplation to connect with this last-mentioned windlass by an extra iron wire a fillet of paper some 6 or 7 inches in width, which would thus be moved, at the rate of about an inch in one minute, over a small table at the hand of the observer. The width of the fillet was intended as a scale of heights above the sun's limb, at about one inch to one minute of arc. In case of the occurrence of any strongly localized mass of light in the corona, such as I myself saw in the elipse of 1869, and in case of its being traced by a powerful spectroscope in advance of the totality, the height from the limb, and the time, could both be instantly recorded together by a pencil-mark, against which, immediately after, could be entered, upon the fillet, the line or lines of the spectrum. I need hardly add here that the aim of this mode of observing would be, by repeated observation of the same object, to trace, if possible, the presence or absence of indications of planetary motion.

I had made at Mr. Browning's a micrometer arrangement of a glass prism of very small angle; but as this was only resorted to in the hurry of the occasion, on account of the facility with which it furnished a micrometer scale, mechanically transferable to the paper fillet, and is objectionable, on the score of its reflecting surfaces, I will not go into the details. As it failed to come into use, I need not say it was excluded on the occasion of the eclipse.

On the day of the eclipse I spent much of the forenoon in an effort still to get the clock-motion ready, the length of the pendulum having been calculated as nearly as practicable. But it became manifest that it was impossible, and I prepared to observe with such means as were ready. The large telescope having been set approximately to the declination of the sun's center, my Italian assistant in a short time learned to follow the sun's diurnal motion, at signal given, with very tolerable success. An extemporized brace was applied in such a manner as to hold the telescope free from shake. In the matter of adjusting the width of the slit of the spectroscope, I deferred to the judgment and great experience of Mr. J. Norman Lockyer, the distinguished head of the English expedition, who was at the same station, and who did me the favor to make the adjustment upon the skylight spectrum. This adjustment remained unaltered till after the totality. As already intimated, the slit of the spectroscope was placed radially to the sun. As the eclipse advanced, the spectroscope system, while clouds did not interfere, was revolved continually to and fro, so as to sweep with the radial slit the entire convex limb of the solar crescent, enabling me to watch the diurnal motion, and to make an occasional rectification of the telescope in declination. As the time of totality approached I began to carry the slit a little beyond either cusp, where nothing remained but the mixed spectra of the sky and corona, but I noticed nothing which I could not see in the skylight spectrum at any time. It may be remarkable that the red chromospheric line did not catch my eye. But in view of the fact that repetition of these trials was speedily cut off by clouds, and in view also of the possibility and probability that the very brilliant full sunlight spectrum left the eye out of condition by the persistence of its impression, I attach very little weight to this negative result. Had my arrangements been completed, the sun's image was to have been screened out without excluding the light external to its limb.

As it now became evident that the total phase was to be lost in an extensive mass of cloud, I turned from the instrument and gave myself to a general survey of the interesting scene around me. The sky in the west was clear to a considerable height above the horizon, of which I had an unobstructed view in that quarter. I watched for the rising of the dark curtain, an appearance mentioned as having been seen by some on the approach of the shadow in the eclipse of 1869. The phenomenon in question was not, however, perceived on this occasion, and subsequent reflection suggested that the smaller diameter of the shadow gave less reason to expect it. The change of the western skylight to the rich ruddy glow which it exhibited, with no distinctly noticeable change, through the whole of the totality, and with a degree of luminosity equal, for aught I can say, to that of evening twilight 30 or 40 minutes after sunset, was quite gradual. The illumination of the landscape around was, I should say, far greater than in the light of the full moon, though very different in the whiteness of the latter. Every object in the landscape continued to be seen with ease and distinctness, much more so than in the moonlight. It is not unlikely that some of this effect might be due to the absence of the deep shadows of moonlight.

At one moment during totality a glimpse of the corona came out through a partially hazy opening in the clouds for a period which I thought did not exceed two seconds. I think it will be to no purpose to state the impression which I got of it under such circumstances.

After the sun again came out, I now took the first available opportunity I had had to test the spectroscope on the full sunlight. Closing up the slit on the solar image I had the satisfaction to see the lines of the solar image come out with a splendor of definition that fully evinced the skill of the maker.

My station was in the gardens of the Convent Benedetti, at Catania.

Among the various arrangements contrived on the voyage to Liverpool, but which could not be attempted, I will briefly mention one in which the observer, without taking his eye from the spectroscope, can by a single movement instantly throw out the prisms and the slit, a reflector taking the place of the former, and disclose to the eye a full view of the object, with the position of the slit marked by a pair of spider-lines. I see that Professor Young has a different arrangement for accomplishing, with similar facility, the same purpose.

Respectfully submitted.

J. HOMER LANE.

Professor BENJAMIN PEIRCE,
*Superintendent of the United States Eclipse Expedition.*

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WASHINGTON, *June* 30, 1873.

DEAR SIR: The following is my report on the observations of the total eclipse of the sun on December 21, 1870. In accordance with your directions I went to Catania to observe the eclipse. I was to have observed it with the same spectroscope and telescope with which I observed the eclipse of 1869, but fitted with Professor Winlock's attachment for recording the position of the spectral lines. Unfortunately, owing to a mistake with which I was in no way concerned, this instrument was dispatched to Spain, and the circumstance was not discovered in time to get the instrument or to go to it. Mr. Adams, of the English expedition, was good enough to lend me an eye-piece with a Savart polariscope. I fitted this to a telescope which I found among the instruments of our own party, in order to observe the nature of the polarization of the corona. I was stationed at the villa of the Marquis di San Giuliano, some three miles behind Catania, on the road to Etna. The weather was remarkably clear in the morning, but a storm blew up at the time of the eclipse, and it was raining during the total phase, at least at the beginning of it. Fortunately, a very small opening occurred in the clouds, so that the observations could be made, although under disadvantageous circumstances. I had previously tested the telescope for polarization, and found none perceptible. The plan was to set first upon the dark face of the moon and turn the polariscope so that the bands disappeared, and then observe the position angle (from the center of the moon) of that part of the corona on which the bands attained their maximum. I observed two parts of the corona, differing 180° in position angle, and found the plane of polarization to be about 6° from the radial position, being more nearly vertical. The parts observed upon were 65° and 145° from the vertex towards the east in position angle. The measures were made upon a part about six or seven minutes from the limb. The measures both of the position of the plane of polarization and of position angle were recorded by scratches upon the lacquer of the eye-piece, the edge of the polariscope affording the means of measuring the latter.

Yours, very respectfully,

C. S. PEIRCE.

Professor BENJAMIN PEIRCE,
*Superintendent Coast Survey.*

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*Report of Mrs. Charles S. Peirce.*

DEAR SIR: My duty as a member of the United States Coast Survey Expedition to the Mediterranean for observing the eclipse of 1870, was to sketch the corona, and I will premise that my knowledge of drawing extends merely to outlinings and shading single objects. That is, I cannot group a landscape rapidly and effectively, but any one object in a landscape I believe I can copy with great accuracy.

After we arrived at Catania, Mr. Lockyer, of the English expedition, kindly lent me a copy of the twelve observations, more or less, which he had drawn up, as being important for the sketchers to make, and these I conned diligently. I also heard, through Professor Peirce, that Mr. Lockyer was advising his sketchers to practice from pictures of former coronas, pinned up on the wall, and to see how many outlines they could dash off in a given time.

I immediately acted upon this hint, but the only copy of a corona of which, as it happened, I could have the use, was one of a former eclipse by Padre Secchi, with what, I must think, exaggerated rays and streamers radiating out from it in all directions. This I pinned high up on my bed-hangings, and copied endless times, by first drawing circles on my paper, and quartering them, and then, always beginning at the left-hand upper quarter, I went through the upper half of the pictured corona, and afterward, starting at the left-hand lower quarter, I carried the lower half round to meet the upper. I also practiced sketching as rapidly as possible the outline of any object that my eye fell upon casually, and I drew frequently the ever-changing steam-cloud that rolls continually out of Etna.

Secchi's picture, however, consisting, as it did, principally of very strongly marked rays, my attention became fixed on the idea of rays, or streamers, and these I was determined, if there were any, to see.

The post of observation of our party was at a villa of the Marquis di San Giuliano, about two miles from Catania. The road to it was that also to Etna, and therefore up-hill all the way. The villa overlooked the valley in which lay Catania and its harbor, and which, set in a wide, encircling frame of mountains on the eastern and western, and of open sea, stretching to the center, horizon, made the most enchanting landscape possible to behold. I was placed at a window in a room of the second story, commanding this view, and with the sun a little to my right hand.

Other reports will, no doubt, describe the sudden change in the weather, which, after the eclipse had begun, converted the most blue and brilliant of skies into one which was covered with clouds. As the eclipse progressed these clouds became denser, and when the sun was nearly covered, they fairly serried themselves into a black wall and hid the phenomenon completely from sight, rain and hail falling at the same time, and a chill blast blowing. Neither the lady with me, nor I, had any watch, and I was convinced, so long the minutes seemed, that the totality and the rain were simultaneous, when suddenly the cloud broke, and left a little lake of clear sky, in which the sun, now nearly extinguished by the black moon, was exhibited as in a frame.

Lest it should prove too dark for me to see to draw, I had been provided with a lantern, but, in my despair of the moments before, I had mechanically blown the candle out, as being no longer needed. Instantly I was nervously anxious to light it again, but the wind was blowing in so strongly from the open window that this was a difficult operation, and while I was struggling to accomplish it, with my eyes down on my table, in a flash, a crimson, almost bloody, light fell upon my paper, throwing black shadows, and I lifted my eyes to the sun just in time to see what I suppose to have been the "Baily's beads," and to catch in the upward sweep of my glance a most tantalizing glimpse of the color-transformation in the clouds, which lined the horizon over the sea and the mountains, and which, in the lurid light, looked as unearthly as dancing witches.

Up to this point, I had steadily watched the landscape, but had seen nothing in the changes of the light more remarkable than the usual appearances of a greenish-black thunder-storm. Indeed, I have seen effects of that kind much more striking than those of this occasion. The color-tints at the instant of the Baily's beads, or vanishing point, however—could one have had thought and eyes for only that—must have been altogether exceptional and peculiar to an eclipse. I, at least, never saw anything approaching the strange and weird effects which that upward glance impressed *en passant* upon my vision.

I had been told to take one look at the corona, as a whole, before beginning to draw, and I did so. But as I never should venture to draw from memory, I am only sure of a thing if I copy it directly from the object. I did not dare to linger over this glance. It was but a second, and most disappointing. The bright halo of the corona immediately surrounding the sun was much narrower than I had supposed, and, as I remember it, it was not pure white, but faintly yellowish, though I can hardly believe that this latter impression is from anything but an imperfect and agitated memory. It, the halo, lost itself suddenly in a confused brightish surrounding that seemed to me a golden mist, so that my belief was, and almost is, that I was looking at the whole thing through a cloud. Let all this, however, go for nothing, since it was too momentary to be correct.

I began to draw, and, even as I had practiced from my pictured corona, I began at the lower side of the left-hand upper quarter and passed round through the right-hand upper quarter. But I could see no bright rays such as I had been copying, only a radiation of dark lines over the bright halo, a few of which I put down as seen in my drawing, just to show the character of them, not as portraits of individual lines. Indeed, I said to myself that it was of no use to try to draw them, because there was, or I thought there was, a cloud over the corona comprising them. I soon turned my eyes and my pencil, therefore, to the lower left-hand quarter. What was my astonishment to find here, not a long and broad bright ray, wide at the base and narrowing to a point, as in Secchi's corona, but a long, dark, or rather delicate gray or steel colored ray, narrowest at the sun and widening as it went out, which entirely crossed the bright halo, and ceased or lost itself only on the very outside edges of the hazy envelope beyond. I put it in its place exactly as it appears in the drawing, and going farther round the diameter, found a more delicate and shorter one about half-way between the two lower quarters, and, further on still, a still shorter one in the upper part of the right-hand lower quarter, and then the eclipse was over, and I had had no time to verify my observation on the lower half, or to scan once more the upper half, in order to see whether there were not some dark rays there which I might have overlooked.

So very delicate was the tint of these rays, so lost in the general halo, and so short was the time, that I doubt, had I not happened to have my attention fixed on the idea of rays alone, whether I should have discovered them at all. Not one of Mr. Lockyer's other twelve questions, by the way, crossed my mind for a moment; nor could they have been answered if they had. The time is too brief, the novelty too complete, and the agitation too great, I am convinced, for a person observing an eclipse for the first time, to see truly more than one point in it. I had not time to allow myself to look at any of the accompanying phonomena, the stars, the light on the landscape, the width of the corona as compared with the diameter of the dark moon, the sphericity of the latter, *anything*. As a whole, the phenomenon was completely lost upon me, and all I brought away with me, all that I can vouch for in what I did see, are my three dark rays. They reminded me somewhat of the way the dark beam across the air looks when the sun is, what the country people call "drawing water," behind a cloud. My first thought in regard to them was, that they were shadows from mountains on the back of the moon, and hence the reader will perceive that the dark rays had something the look of a shadow thrown across a luminous object. I remembered that all the photographs (not drawings) I had seen of eclipses had a decided notch in the outline of the corona, about the neighborhood of my first dark ray, which induced me to think that the appearance might be something permanent. Professor Peirce thought that the observations of the dark rays was new and might be important. I mentioned it to one or two of the scientific gentlemen then in Catania, but they listened as if they thought my imagination had as much to do with my impression as the facts, and it was not until we got to London and heard about the comparison of Professor Winlock's and Mr. Brothers's photographs in regard to the position of these very rifts, that I felt sure I had seen anything worth seeing.

Mr. Lockyer, in one of his published comments on the eclipse in *Nature*, said, I believe, that "none of the sketchers in Sicily had seen the rift." I was in the hotel with Mr. Lockyer, but he had not thought it worth while to ask me what I had observed, and I did not like to volunteer the information, especially as the English parties in Catania and upon Etna had been deprived by the rain of seeing the eclipse at all.

In future eclipses it would, perhaps, be well that every two sketchers should take one point between them. Thus they will have time to make a definite observation of value, and to correct each other by comparing notes. Had it not been for the photographs, my observation would hardly have been credited. Yet, Professor Winlock's photograph so nearly bears out my observation of the position of the dark rays on the lower half of the corona, that I can feel no doubt that I really saw what I have here attempted to picture and describe.

The drawing represents the eclipse as it appeared to the naked eye, and the vertical direction is up and down on the sketch.

Yours, very respectfully,

ZINA FAY PEIRCE.

Professor BENJAMIN PEIRCE,
*Superintendent Coast Survey.*

HEADQUARTERS, BATTALION OF ENGINEERS,
*Willett's Point, N. Y. H., February* 9, 1871.

SIR: I have the honor to submit the following report upon the duties which you assigned to me during the recent solar eclipse in Sicily:

My instruments consisted of a comet-seeker, having a large field of view, (magnifying power about 8,) and a good Casella aneroid barometer, designed to be carried on the person like a watch. My station was the highest attainable point on Mount Etna. My duties were to study the physical characteristics of the corona.

In company of Professor Silvestri, of the University of Catania, and a party of five English astronomers, I proceeded on December 21 to the Casa Ferentina, a small hut on the side of Mount Etna, elevated about 4,950 feet above the sea. Here we spent a stormy night. At daylight on the 22d snow was still falling heavily, but about 8 a. m. the weather cleared.

Leaving the rest of the party at the casa, I proceeded up the mountain with a guide. The soft snow, varying in depth from 6 inches to 2 feet, made the route impassable for mules, and a gale of wind, loaded with particles of sleet, which blew strongly in our faces, rendered the ascent exhausting. By noon an elevation of 8,736 feet above the sea had been reached, at a point near the summit of Montagnuola. The smoke blowing from the crater made a further ascent inexpedient. A station was accordingly selected, as well sheltered from wind as possible, and every preparation was made for observing. The clouds, in cumulose masses, were all far below us, and first contact occurred under favorable circumstances, which gave every promise of continuance. Suddenly, however, the mountain was enveloped in a cloud which soon produced a storm of hail that rattled among the ice and lava with a sound like the breaking of glass. The gradual loss of light began to give an inky tinge to the deep gray of the storm; totality was rapidly approaching, and, there being no prospect of a favorable change, at fifteen minutes before the instant, I started down the mountain with all possible speed, vainly hoping to escape from the cloud. At an elevation of 7,500 feet I was overtaken by the shadow, which swept with great rapidity over us, darkening the gloom to an awe-inspiring degree. The amount of light was sufficient to render ordinary type visible, but the peculiar ghastly effect was like nothing usual in nature. After continuing about a minute, this gave place suddenly to a rosy red tint, which lasted fully a minute and then gradually changed to the former inky gray. In a moment or two more I had a glimpse of the sun's crescent, resembling that of the earliest new moon.

This peculiar action of clouds in absorbing least the red rays of the feebly-returning light is, I regret to say, the only result of my observations. Possibly it may serve to explain the color sometimes observed in the corona when viewed through a hazy atmosphere.

I append the following barometrical observations to illustrate the surprising accuracy of the little instrument, which was no larger than an ordinary watch. It was corrected for temperature by the maker; but, being carried in the pocket, was not subjected to much change in this respect. It was read carefully by microscope. Some of the air-temperatures are only approximate. The altitude of the station in Catania has been assumed at 50 feet.

| Date. | Hour. | Station. | Air-temperature. | Barometer. | Intermediate altitude. | Altitude above sea. |
|---|---|---|---|---|---|---|
| 1870. | | | *Fahr.* | *Inches.* | *Feet.* | *Feet.* |
| December 21 | 7 a. m. | Catania | 52 | 29.90 | .......... | 50 |
| 21 | 9.15 a. m. | Nicolosi | 50 | 27.50 | 2,287 | 2,337 |
| 21 | 2 p. m. | Casa Ferentina | 47 | 25.00 | 2,591 | 4,928 |
| 22 | 8.45 a. m. | ......do | 35 | 24.58 | .......... | .......... |
| 22 | 12 m. | Highest station | 15 | 21.21 | 3,808 | 8,736 |
| 22 | 1.30 p. m. | ......do | 15 | 21.17 | .......... | .......... |
| 22 | 2.10 p. m. | Totality station | 20 | 22.20 | 1,206 | 7,530 |
| 22 | 3.30 p. m. | Casa Ferentina | 45 | 24.44 | 2,544 | 4,986 |
| 22 | 6.45 p. m. | Nicolosi | 45 | 26.92 | 2,608 | 2,378 |

The computations have been made by the usual formulæ, applied from station to station, and the different altitudes thus deduced for the same place in ascending and descending, furnish the following checks upon the accuracy of the work:

| | | |
|---|---|---|
| Nicolosi ........ | ascending, | 2,337 feet. |
| | descending, | 2,378 feet. |
| Casa Ferentina.. | ascending, | 4,928 feet. |
| | descending, | 4,986 feet. |

In closing, permit me to express to you, sir, my appreciation of the official and personal courtesy which has rendered the expedition a most pleasant one to me.

I am, sir, very respectfully, your obedient servant,

HENRY L. ABBOT,
*Major of Engineers and Brevet Brigadier-General.*

Professor BENJAMIN PEIRCE, *in charge of Solar Eclipse Expedition.*

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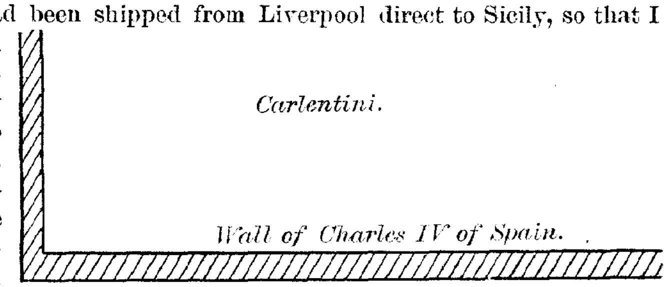
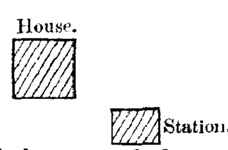
REPORT OF OBSERVATIONS OF THE TOTAL SOLAR ECLIPSE OF DECEMBER 22, 1870, MADE AT CARLENTINI, SICILY, BY JAMES C. WATSON, PH. D., DIRECTOR OF THE OBSERVATORY AT ANN ARBOR, MICHIGAN.

ANN ARBOR, *March*, 1871.

DEAR SIR: Having received an invitation from you to join your party in Sicily to observe the solar eclipse of December 22, 1870, I have the honor to transmit to you the following report of my observations:

I left Ann Arbor the latter part of October and proceeded via England and the continent, reaching Catania on the 17th of December. After consultation with you and with Dr. Peters, I finally, with your approval, selected the village of Carlentini, twenty-one miles south of Catania, and very near the central line of the eclipse, as my observing-station; but on account of the reputed unhealthiness of this village to a person not acclimated, I did not go there until the day of the eclipse. My telescope and stand had been shipped from Liverpool direct to Sicily, so that I found them in Catania upon my arrival there, and having decided upon observing simply the phenomena presented by the corona, it was not necessary for me to convey other instruments to Carlentini. Accompanied by your courier as a general assistant, I left Catania early on the morning of December 22 by special conveyance, and reached Carlentini at 11 o'clock. I had been provided with a letter of introduction to MM. Alfio and Luigi Modica, prominent citizens of the place, and I found upon my arrival that they had already been advised of my intended visit and of its object, and that they had already selected various positions which seemed to them convenient as stations for observation. Having examined the localities suggested by them, I finally decided to observe from a point just outside the south wall of the town, where I would, from the nature of the ground, be protected from the wind, which was blowing quite briskly. There was no opportunity during my stay in Carlentini to determine the geographical position of my station; but it may be easily determined from the data of the trigonometrical survey of the island in the possession of the Italian government. The station was 200 feet south of the south wall known as the wall of Charles IV of Spain, and 100 feet east of its southwest corner, as shown by the above diagram.



Mr. Modica informed me that the house near which I observed is 400 yards due south from the pillar erected near the north entrance to the town for the trigonometrical survey. It is quite probable that the position of the southwest corner of the wall is recorded in the results of the survey. The town is situated on a hill about 500 feet in height, it being the ridge separating the valley of Catania from that of Agosta and Syracuse. The telescope which I used was an excellent one, constructed by Alvan Clark & Sons, and belonging to the high school at Grand Rapids, Michigan. Its aperture is 3¾ inches, and tests under a great variety of circumstances have convinced me that its optical performance cannot be excelled by any instrument of its size. My experience in the case of the total eclipse of the sun in 1869 admonished me that the interval of totality would quickly pass; much more so than one actively engaged in observing would suspect, and that if I attempted too much I should fail in all. I therefore determined to observe with a power of about 40, which gave me a sufficiently extended field and the most perfect definition. Although I had determined to observe chiefly the phenomena of the corona at the time of totality, yet there was of course opportunity, without interfering with my plan, to observe the first and last contacts, and to make observations of the cusps and of other phenomena as the eclipse progressed.

When I left Catania, in the morning, it was raining, and the prospect for clear weather was anything but favorable. About 9 o'clock the clouds broke up, and shortly afterward the sky was quite clear in all directions, except in the immediate neighborhood of Mount Etna, around which the low clouds seemed to hover. From my station, at 12 o'clock, the prospect for clear weather during the remainder of the day was good.

The first contact was observed at—

$18^h\ 4^m\ 13^s.0$ chronometer time.

The moon's limb bisected the umbra of the first two spots at—

$18^h\ 27^m\ 17^s.0$.

And it bisected the umbra of the second spot at—

$18^h\ 33^m\ 13^s.0$.

It also bisected the nucleus of a smaller spot, near the sun's center, at—

$18^h\ 38^m\ 27^s.0$.

During the progress of the eclipse I watched the cusps attentively, and they remained constantly sharp at the extremities, there being no blunting whatever. The atmosphere was remarkably steady and the definition excellent. At about $18^h\ 50^m$, chronometer time, a bank of clouds appeared in the west rising rapidly, and in a few minutes the sky was entirely overcast. I sent the courier to the top of the wall to report as to the prospects around us, and he reported dense clouds in all directions, with a rain storm in the neighborhood of Catania.

The high expectations created by the favorable beginning, gave place to an indescribable anxiety at the prospect now before me. It seemed the very greatest misfortune that my long journey was to be without any scientific reward. It gave me some consolation, however, to know that my distress was sympathetically shared by the gentlemen present, and it is but just to say that the enthusiasm at the *denouement* was as strikingly manifested. While all appeared thus hopeless, suddenly a ray of promise gleamed through a small break in the great cloud which covered the sun; by degrees this became wider and wider, until at last, just four minutes before totality was to begin, the cloud parted, one part passing to the northward in the valley south of Etna, and the other passing to the south, so that during the whole of totality, and afterwards, with only a single interruption, until near the time of the last contact, I had the good fortune to observe in the clearest and purest sky imaginable.

The moments for observing the corona during the totality being so precious, I did not venture to observe the time of the second contact; but Mr. Modica observed it with a small refractor, power about 50, at

$19^h\ 27^m\ 10^s.0$ chronometer time.

The third contract was not observed, since the gentlemen present were so struck by the grandeur of the scene that they remained, as it were, spell-bound until the light had again burst forth. I had requested MM. Modica, whom I found to be an accomplished gentlemen, and well versed in solar physics, to make sketches of the corona for me, and I had prepared sheets for them, with reference-points marked on them; but when the totality had passed, in answer to my question as to what they had recorded, they showed me the sheets without any additional trace, and with a shrug of the shoulders and a gesticulation of sublimity, they said it had passed so soon that they could not "think to make one mark."

Before proceeding to state particularly the results of my observations during the totality, I will complete in this connection the statement of the results as to the times of the contacts. I observed the last contact through a bank of thin clouds, at

$20^h\ 47^m\ 41^s$ chronometer time.

The times were noted by a pocket-chronometer made by the National Watch Company of Elgin, Illinois. It had maintained its rate well during the long journey from Ann Arbor to Catania, and hence it was relied upon for these observations. It was compared with the standard chronometers at the observing station of Mr. Schott, in the Benedictine Garden at Catania, on the days preceding and following that of the eclipse. The comparisons gave the following results:

1870, December 21, $21^h\ 42^m$ chronometer time. Hornby 1107, chronometer $6^h\ 32^m\ 18^s.0$.
21 50 chronometer time. Kessels 1287, chronometer 18 24 57.5

The errors of Hornby and Kessels, for these instants, were determined by Mr. Schott, as follows:

Hornby 1107, $22^s.0$ slow on Catania mean time.
Kessels 1287, $6^h\ 7^m\ 40^s.3$ slow on Catania sidereal time.

Hence the error of my chronometer was the following:

1870, December 21, $4^h\ 18^m$ Catania mean time. Correction to chronometer $= +\ 6^h\ 32^m\ 39^s.8$.

The comparisons in the forenoon of the day after the eclipse gave:

1870, December 22, $15^h\ 20^m$ chronometer time. Kessels 1287, chronometer $18^h\ 31^m\ 45^s.0$.
15 49 chronometer time. Hornby 1107, chronometer 6 32 22 .3.

And for these instants Mr. Schott gave me the following corrections:

Kessels 1287, $6^h\ 7^m\ 39^s.2$ slow on Catania sidereal time.
Hornby 1107, 0 15 .5 slow on Catania mean time.

Hence the error of my chronometer is found to be:

1870, December 22, $22^h\ 8^m$ Catania mean time. Correction to chronometer $= +\ 6^h\ 32^m\ 37^s.2$.

The observed contacts at Carlentini are therefore the following:

| | Catania mean time. | Observer. |
|---|---|---|
| | *h. m. s.* | |
| First contact | 0 36 51.6 | Watson. |
| Bisection of first spot | 0 59 55.6 | Watson. |
| Bisection of second spot | 1 5 51.6 | Watson. |
| Bisection of third spot | 1 11 5.6 | Watson. |
| Beginning of totality | 1 59 48.5 | Modica. |
| Last contact | 3 20 19.4 | Watson. |

The difference of longitude between my station and the American station in the Benedictine Garden at Catania, may be obtained from the data given by the trigonometrical survey of the island of Sicily, and then these times may be reduced to Carlentini mean time.

As already stated, a few minutes before the totality began the cloud broke and gave us perfectly clear sky in the neighborhood of the sun. Just before the second contact I noticed the formation of Baily's beads, but only such appearances as would result from the irregularities of the moon's limb. I also noticed one bright prominence near the south point of the limb about fifteen seconds before the total obscuration. The corona was also visible at the same time. As soon as the last rays of the photosphere disappeared, I immediately sketched, with the naked eye, the outline of the bright corona, and having completed its trace I compared the sketch with the sun in order to be assured of its accuracy. Then, without loss of time, I placed my eye at the telescope already adjusted for sharp definition. In the first place I moved the telescope around the limb of the moon to see whether the outline and extent of the corona agreed with the sketch already made, and having assured myself of this fact, I then sketched the places of the principal prominences as reference points for the positions of remarkable indentations in the corona which were conspicuous in passing round it. Having sketched the places and the form of these indentations, I then studied carefully, for a few moments, its structure, and sought to notice particularly whether any changes whatever took place. As soon as I saw that the totality was about to end, I again traced the outline of the corona as visible to the naked eye, and the total phase, lasting one hundred and ten seconds, had passed. Fully sensible of the impossibility of sketching more than outlines during the short period of totality, I did not attempt more, and I was thus enabled to devote attention to details of structure and to other phenomena which would otherwise have passed unnoticed. The sketches were made in my note-book with pencil; but as soon as the totality had passed, I sat down and wrote out full explanations of the meaning of the marks made, as well as full descriptions of the phenomena which I observed. Upon returning to Catania, I spent the greater portion of the next three days in making, from these sketches—while everything connected with the appearance of the corona was vivid in my mind, and before I could be influenced in my judgment by any reports of what was seen by others—two crayon drawings, which I send you with this report, the first showing the corona as it appeared to the naked eye, the other showing it as it appeared in the telescope. But, before proceeding further with statements in regard to these drawings, I will mention particularly some of the phenomena which I observed. As seen by the naked eye there was a bright band of light, about one-third the solar radius in extent, completely surrounding the sun. The outline of its exterior portion was well defined, but irregular; and near the lower limb, and to the right, was a conspicuous indentation, while on the eastern limb, where the width of the corona was on the average a maximum, there were fainter indentations. Immediately outside of this bright corona was a second or fainter one extending out until it faded away at perhaps a distance from the moon's limb equal to the sun's radius, although I recorded it as being distinctly seen at a distance of only two-thirds of the solar radius. From the beginning to the end of the total phase the bright solar corona, so far as I could see, was absolutely constant both in form and in brilliancy, but I noticed that the exterior or faint corona was first brighter and more extensive on the eastern limb at the beginning of totality, and then perceptibly brighter on the western side as the total eclipse ended. This change of brilliancy of the exterior faint corona led me to think at the time that this portion of the corona is non-solar, and that it was due to the illumination of our atmosphere by the bright light of the inner or solar corona, and I see no reason yet to change the opinion thus formed, although possibly it might have been due in part to particles of matter in the neighborhood of the sun, but not connected with it directly.

As seen in the telescope the phenomena presented to the naked eye were more distinct. The extent and the outline of the inner bright corona were the same, but the faint indentations which were visible to the naked eye here appeared to extend down to the limb of the moon, giving the appearance of a cusp quite deeply shaded at the point and gradually becoming brighter and brighter, until at the limit of the corona it was somewhat brighter than the external halo. This external halo seemed thus to envelope the inner corona like a veil. The positions of these cusps were carefully noted by reference to neighboring prominences. They were bounded by regular curved outlines with opposing convexities. The points were sharp, and I noticed particularly that the moon in passing along occulted them precisely as it did the prominences. There were three of these cusps on the eastern limbs and one on the lower limb, and a little to the right, as seen by direct vision.

The positions of these cusps measured from the vertex of the sun toward the east were approximately as follows:

| | |
|---|---|
| First cusp | 26° |
| Second cusp | 93° |
| Third cusp | 142° |
| Fourth cusp | 220° |

These angles, it must be understood, are not the results of exact measurements, but simply the mean of the results obtained by estimation from two independent sketches of their relative positions. Their position in reference to neighboring prominences are correctly shown on the drawings, and when the exact places of these prominences shall have been determined, we may thus derive more exact values. The first three of these cusps were more distinct as seen in the telescope than the fourth, but not quite so large. An examination of the coronal parts between these apparent indentations, which I have called cusps, showed that for a distance of perhaps one minute from the limb it was of intense uniform brilliancy, then passing outward were streams of luminous matter, extending to near the outer extremity of the corona, where they were again blended together into a bright even band which marked the limit of what appeared to be the real solar corona. These radiating streams were separated by more faintly illuminated interstices, and thus gave indications at some points of an apparent radial structure of the corona. In the vicinity of the cusps these lines were curved conformably to the cusp, the curvature becoming less and less receding from the cusp, until, at a point midway between two cusps, the lines or streams were radial. This structural form was most distinct on the eastern limb, and in the immediate vicinity of the cusps. The fine definition of the telescope was shown during these observations by a view of Saturn which I obtained in sweeping round the contour of the corona.

I thought at first that I could see an apparent connection between the distribution of the prominences and the divisions in the corona, but the brief period of observation did not permit me to determine anything definitely on that point. I did not venture to attempt to sketch more than the principal prominences as sure points of reference, and I think it quite possible that when the places of all the prominences then visible are known, some connection of this kind will be evident. It was apparent to me that the extent of the corona was directly connected with the prominences, and after my drawing, showing its outline, was completed, I was informed by Mr. Seabrooke, of the English party, that he had mapped all the prominences on the day of the eclipse and not long before its commencement by means of the spectroscope. We subsequently compared his map with my drawing, and the intimate relation which I had suspected was completely shown. Where, by his map, there were high prominences, there was shown in my drawing a corresponding extension of the corona, and where there were no prominences my drawing showed the corona at its minimum.

The drawings, which I send you herewith, were made with crayons, from the outlines traced and descriptions recorded at the time of the eclipse as already stated. For facilities in this work I am indebted to Mr. Darwin, of the English party, who had intended to sketch the corona from the cone of Mount Etna, but having been so unfortunate, after ascending nearly 6,000 feet, as to be in a terrific snow-storm during the whole of the eclipse, he was not permitted to realize his plan, and hence he very kindly turned over to me the paper and the crayons. Having been thus provided with means of completing the delineations which I had sketched, I determined to make the drawings before I left Catania, while everything connected with the observations was vividly impressed upon my mind, although I had taken the precaution to write out full descriptions of the phenomena observed and explanations of the marks which I traced in my pencil sketches in my note-book, to be available for the completion of the drawings at any subsequent time. Not being skilled in crayon drawings I found great difficulty in attempting to delineate what I saw. I send you the drawings as I made them at Catania, fearing that if I attempt to improve them I may interfere in some way with the evidence which they afford. I will therefore endeavor to state wherein they do not convey precisely the idea which I wish to communicate.

First, then, in respect to the drawing representing the corona as seen by the naked eye. The outline of the solar corona is perhaps too marked in contrast with the light of the secondary corona, if viewed in close proximity and with a strong light. It conveys best the correct impression if you place it in a moderate light admitted from the side, and view it at a distance of about 15 or 20 feet, so that the contrast between the outer and the inner or solar corona is not too vivid. The color of the moon is too dark; it should be of a deep neutral tint. The corona also should indicate a pearl-white vivid light nearest the limb of the sun, and fainter somewhat at its extremity. There were no prominences visible distinctly to the naked eye as in the case of the total eclipse in 1869, but the effect was apparently to intensify the light of the corona in the places where the telescope revealed them.

The second drawing gives the telescopic view of the corona. The positions and the form of the cusps are correctly indicated. The streams of light already mentioned are also shown, but I did not succeed, with the crayons which I had at hand, in giving precisely the correct delineation. The form of these streams and their relation to the cusps are indeed clearly indicated, but there was a general effect which, having failed to indicate sufficiently in the drawing, I will attempt to describe.

The appearance in the telescope reminded me of the great comet of 1858, which I observed attentively. There was in the corona first a uniform band of light, pearl-white, as in the case of the bright comets, then streams of luminous matter flowing out, and afterward spreading and uniting, thus forming a shell-like envelope to the sun. It seemed as if the cusps were merely rents in this envelope, and as if I were looking into a partially transparent shell, within which was a brilliant core emitting luminous streams. The manner in which the exterior halo enveloped the solar corona is not exactly shown in my drawing. The cusps were dark at the apex, and quite bright at the extremity of the corona, but not nearly so bright as the other portions of the corona, so that, being of a brilliancy not much in excess of that of the outer halo, the appearance was that of the formation by the latter of a sort of envelope passing down into the indentations of the former. The color of the moon should be of a deep neutral tint, and the prominences should be of a light rosy tint. They were not so red as in 1869, but exhibited a more glowing intensity of light.

In conclusion, permit me to say, that, being fully convinced from these observations that the bright corona whose limit was well defined is really an appendage of the sun, composed of glowing gas, I concluded to observe carefully whether it might not be visible during the partial eclipse, and I was able to see it distinctly, by the visibility of the limb of the moon beyond the limb of the sun. At $20^h\ 38^m$ chronometer time, or only ten minutes before the last contact, I could distinctly trace the limb of the moon to a distance of two minutes of arc from the sun's limb. Hence I venture the prediction that a careful scrutiny will show the corona during any partial eclipse, and I conceive it to be very possible indeed that the Janssen-Lockyer method may be extended so that the corona may be studied at all times, as well as the prominences. If I am not mistaken as to the indications of what I saw and what I have here recorded, the attempt ought to be made.

Thanking you very sincerely for your kind invitation to take part in the expedition, I submit through you to the world this statement of the results of my observations, with the hope that they may be regarded as having some value in perfecting our knowledge of the physical constitution of the sun.

I have the honor to be, sir, yours, very truly,

JAMES C. WATSON.

Professor BENJAMIN PEIRCE,
*Superintendent of the United States Coast Survey.*

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REPORT OF OBSERVATIONS OF THE TOTAL SOLAR ECLIPSE OF DECEMBER 22, 1870, MADE AT JEREZ DE LA FRONTERA, BY JOSEPH WINLOCK.

SIR: In the autumn of 1870, I undertook at your request the organization and direction of a party to be employed in observing the total solar eclipse of December 22, in the same year.

The place which I selected for the observations was Jerez de la Frontera, in the south of Spain, near Cadiz. The advantages of this station known to me at the time were that it lay near the central line of the eclipse, and was connected by railroad with Cadiz. The climate of the whole of Southern Spain was known to be on the whole favorable to observations, but I could gather no definite information as to the climate of Jerez itself as compared with other Spanish stations. I was gratified to learn, on my arrival there, however, that the chance of clear weather in the southwest of Spain is at least equal, and probably superior, to that at stations farther east. In confirmation of this view, I subjoin a statement compiled from a meteorological record kept between August 15, 1864, and September 30, 1870, at the house of Mr. Richard Davies, in Jerez. A thermometer at a distance from any building would no doubt show a larger range of temperature than is apparent from this record. The thermometer was observed at 8 a. m., 12 m., 3 p. m., 8 p. m.

*Highest temperature, in degrees of Fahrenheit, recorded during—*

| | Jan. | Feb. | March. | April. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1864 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 87 | 88 | 73 | 67 | 62 |
| 1865 | 66 | 64 | 64 | 70 | 80 | 85 | 88 | 86 | 87 | 80 | 70 | 64 |
| 1866 | 63 | 64 | 69 | 74 | 76 | 84 | 90 | 94 | 86 | 82 | 77 | 74 |
| 1867 | 69 | 71 | 72 | 79 | 85 | 87 | 92 | 88 | 87 | 80 | 73 | 67 |
| 1868 | 65 | 63 | 70 | 74 | 83 | 88 | 85 | 89 | 89 | 76 | 66 | 65 |
| 1869 | 63 | 65 | 64 | 70 | 72 | 76 | 93 | 88 | 85 | 83 | 65 | 61 |
| 1870 | 61 | 58 | 68 | 74 | 80 | 87 | 92 | 89 | 85 | ...... | ...... | ...... |

*Lowest temperature, in degrees of Fahrenheit, recorded during—*

| | Jan. | Feb. | March. | April. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1864 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 74 | 66 | 60 | 56 | 48 |
| 1865 | 50 | 49 | 52 | 56 | 60 | 68 | 70 | 71 | 71 | 63 | 58 | 46 |
| 1866 | 48 | 50 | 52 | 56 | 61 | 63 | 68 | 70 | 66 | 62 | 57 | 55 |
| 1867 | 52 | 54 | 54 | 59 | 62 | 68 | 70 | 70 | 67 | 62 | 56 | 46 |
| 1868 | 48 | 51 | 53 | 56 | 62 | 69 | 72 | 71 | 65 | 63 | 57 | 55 |
| 1869 | 53 | 56 | 56 | 57 | 66 | 67 | 73 | 75 | 70 | 60 | 52 | 48 |
| 1870 | 47 | 51 | 57 | 57 | 62 | 72 | 73 | 72 | 73 | ...... | ...... | ...... |

*Number of days which seem to have been generally cloudy.*

| | Jan. | Feb. | March. | April. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1864 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 3 | 2 | 6 | 1 | 5 |
| 1865 | 9 | 6 | 5 | 8 | 9 | 0 | 1 | 3 | 4 | 5 | 10 | 3 |
| 1866 | 7 | 9 | 8 | 6 | 4 | 3 | 0 | 0 | 1 | 1 | 8 | 3 |
| 1867 | 15 | 3 | 11 | 3 | 4 | 1 | 1 | 2 | 1 | 5 | 5 | 8 |
| 1868 | 7 | 10 | 5 | 2 | 4 | 4 | 1 | 2 | 5 | 1 | 11 | 14 |
| 1869 | 6 | 4 | 6 | 4 | 5 | 2 | 0 | 1 | 2 | 2 | 6 | 10 |
| 1870 | 9 | 1 | 5 | 3 | 1 | 1 | 0 | 1 | 2 | ...... | ...... | ...... |
| Mean | 8.8 | 5.5 | 6.7 | 4.3 | 4.5 | 1.8 | 0.5 | 1.7 | 2.4 | 3.3 | 6.8 | 7.2 |

*Number of days on which rain is recorded to have fallen.*

| | Jan. | Feb. | March. | April. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1864 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 1 | 2 | 16 | 2 | 10 |
| 1865 | 14 | 8 | 5 | 11 | 6 | 1 | 1 | 3 | 5 | 5 | 15 | 4 |
| 1866 | 6 | 7 | 12 | 10 | 10 | 5 | 0 | 0 | 2 | 6 | 2 | 4 |
| 1867 | 14 | 3 | 12 | 2 | 7 | 2 | 0 | 1 | 3 | 3 | 7 | 5 |
| 1868 | 7 | 6 | 3 | 6 | 2 | 2 | 0 | 2 | 7 | 1 | 12 | 8 |
| 1869 | 6 | 4 | 9 | 1 | 8 | 3 | 0 | 3 | 2 | 3 | 7 | 10 |
| 1870 | 8 | 7 | 6 | 4 | 3 | 3 | 1 | 1 | 4 | ...... | ...... | ...... |
| Mean | 9.2 | 5.8 | 7.2 | 5.7 | 6.0 | 2.7 | 0.3 | 1.6 | 3.6 | 5.7 | 7.5 | 6.8 |

*Number of nights in which rain is recorded to have fallen.*

| | Jan. | Feb. | March. | April. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1864 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 1 | 2 | 3 | 7 | 4 |
| 1865 | 3 | 3 | 6 | 2 | 1 | 1 | 1 | 0 | 0 | 2 | 2 | 3 |
| 1866 | 2 | 4 | 4 | 0 | 0 | 2 | 0 | 0 | 1 | 4 | 2 | 2 |
| 1867 | 4 | 0 | 3 | 1 | 1 | 3 | 0 | 0 | 0 | 1 | 0 | 1 |
| 1868 | 3 | 0 | 1 | 3 | 0 | 0 | 0 | 2 | 5 | 1 | 0 | 3 |
| 1869 | 2 | 0 | 0 | 0 | 2 | 0 | 1 | 2 | 4 | 2 | 1 | 4 |
| 1870 | 4 | 1 | 4 | 4 | 1 | 0 | 0 | 3 | 2 | ...... | ...... | ...... |
| Mean | 3.0 | 1.3 | 3.0 | 1.7 | 0.8 | 1.0 | 0.3 | 1.1* | 2.0 | 2.2 | 2.0 | 2.8 |

The party under my direction consisted of the following gentlemen: Mr. G. W. Dean, assistant United States Coast Survey; Professor C. A. Young, of Dartmouth College; Captain O. H. Ernst, United States Army; Professor S. P. Langley, Western University, Allegheny, Pennsylvania; Professor E. C. Pickering, Massachusetts Institute of Technology; Mr. Alvan G. Clark, of Cambridgeport, Massachusetts; Mr. Henry Gannett, assistant at Harvard College Observatory; Mr. O. H. Willard, of Philadelphia, photographer to the expedition, and his assistant, Mr. Mahony; Mr. Ross, assistant to Professor Pickering; Mr. J. White, of Cambridge, Massachusetts, carpenter to the expedition. Three gentlemen whom I met in Spain, as will hereafter be stated, Mr. Gordon, Mr. Norman, and Mr. Pye, also assisted me in the observations of the eclipse.

The instruments furnished for the expedition by Harvard College Observatory were as follows:

1. Equatorial telescope from west dome, aperture $5\frac{1}{4}$ inches.
2. Equatorial, ordinarily used as the finder for the large telescope of the observatory; object-glass by Merz, aperture 4 inches.
3. Equatorial, aperture 3 inches, mounted on brass stand of Bowditch comet-seeker.
4. Comet-seeker, with reflecting prism, and eye-piece at end of axis; aperture 4 inches.
5. Small telescope, bought of G. M. Searle, with equatorial mounting; aperture 3 inches.
6. Lerebour's telescope, on stand; aperture 3 inches.
7. Quincy comet-seeker; aperture $2\frac{1}{2}$ inches.
8. Telescope of 6 inches aperture, mounted equatorially, with clock-work from west dome, for taking photographs; lens corrected for the chemical rays.
9. Stationary telescope for instantaneous photographs, with plane mirror to throw the sunlight upon the lens; aperture 4 inches, focal length $32\frac{1}{2}$ feet.
10. Spectroscope by Troughton & Simms, with two prisms of flint-glass.
11. Spectroscope by Alvan Clark & Sons, with one flint-glass prism.
12. A telescope of 8 inches aperture, with equatorial mounting and clock-work, borrowed from Messrs. Alvan Clark & Sons, for use in photography.

Also various smaller instruments and apparatus belonging to Harvard College Observatory, among which may be mentioned a transit theodolite by L. Casella, No. 3129; a chronometer with galvanic recording attachment, by C. Frodsham, No. 3451; cameras for the photographic telescopes.

The United States Coast Survey furnished transit instrument No. 5 and chronograph No. 2; also a chronometer with galvanic recording attachment. Dartmouth College sent an equatorial telescope, four spectroscopes, a comet-seeker, and other instruments, which will be found described in the report of Professor Young. Professor Langley brought a small portable telescope, a Savart's polariscope, and a polarizing solar eye-piece. Professor Pickering also brought apparatus for observing polarization. Captain Ernst brought a sextant and several small telescopes; and Mr. Willard was provided with photographic materials.

I left New York by the Cunard steamer of November 3, and proceeded, by the steamer leaving Southampton November 19, to Gibraltar, where I arrived November 26; and thence, three days later, went to Cadiz. The instruments, which were left at Liverpool in charge of Mr. A. G. Clark and Mr. White, arrived soon after, and were, without much delay, passed through the custom-house, the officials at Cadiz, to whom I take this opportunity of expressing my thanks, being disposed to accommodate the expedition as much as possible. I have also to acknowledge my obligations to General Duffie, our consul at Cadiz, for his courtesy and assistance.

Through the kindness of our vice-consul at Cadiz, Mr. Younger, I was made acquainted with Mr. Richard H. Davies and his brother, wine-merchants, of Jerez. The kind attentions of these gentlemen made the selection of a place for the observations and the mounting of the instruments a comparatively easy task. Mr. Davies at once placed at our service his own country-seat, "Olivar de Buena Vista," which I directly perceived to be admirably suited to the wants of the expedition, from its buildings, its convenient distance from the city, and its proximity to the telegraph line which I expected to use in determining the difference of longitude between our station and the observatory of San Fernando. I also obtained from Señor Riviero, through the intervention of Mr. Gordon, leave to occupy his estate, called "Recreo," which is situated about three-eighths of a mile north-northwest from the station at "Olivar." The roof at this place furnished a fine position for the small instruments and for observations of polarization and of general phenomena, while the heavier instruments which required to be placed upon the ground, and needed no extended view of the heavens, found ample accommodations at "Olivar."

I considered the expediency of dividing the party and sending some of them to Marbella, or Estepona, or into the mountains in the neighborhood of Jerez; but I became satisfied that no advantage could be expected from this. Those best informed upon the subject assured me that the only wind that could bring harm to us would be equally disastrous to stations on the Mediterranean; and my own observations at Gibraltar and elsewhere, of the manner in which clouds collected about the Spanish mountains, convinced me that it would be better to avoid the high land. I therefore concluded to keep the party together at Jerez, and the result seems to have justified this decision.

I reached Jerez on December 5, and by December 9 all my party were upon the ground. In spite of the difficulty of procuring lumber, referred to in the report of Mr. Dean, all the preparations for the observation of the eclipse were completed in due season, and each observer's work had been assigned to him. As the reports of other members of the party contain full details of the work undertaken by them, I have but little to add before giving an account of the photographic work and of my own observations.

A telescope and spectroscope, Nos. 2 and 11 in the list of instruments, had been intended for the use of Mr. C. S. Peirce, in Sicily, but by an accidental misunderstanding were brought to Jerez with the other instruments. Under these circumstances, I at first intended to assign this telescope and spectroscope to Professor Langley, but as he preferred to observe with the polariscope, the spectroscope was detached and assigned to Mr. Pye, who used it with a small hand-telescope, placed in front of the slit, and corroborated Professor Young's very important observation of the "spectrum filled for an instant with bright lines."

Mr. Pye, Mr. J. C. Gordon, and Mr. Norman, who have been mentioned above, were English gentlemen of scientific tastes, who kindly offered me their assistance in Spain, and formed a valuable addition to our corps of observers, Mr. Gordon and Mr. Norman being most accomplished draughtsmen. Mr. Gordon used his own telescope of about 3 inches aperture, mounted on a tripod stand, and made the sketch, plate 4; his report will be found below. Mr. Norman, unluckily, had an instrument which rendered his skill in sketching of little avail.

The stationary telescope, No. 9 in the list of instruments above, was used by Mr. Gannett in photographing the full disk of the sun, and the partial phases of the eclipse; two of these photographs are represented in plate 1. It was part of my plan to take simultaneous pictures of partial phases with the three photographic telescopes, and by means of micrometric measurements of the negatives to test the relative and absolute accuracy of the work done by each telescope. But the unfavorable weather of the day of the eclipse prevented the satisfactory execution of this project.

Telescopes Nos. 8 and 12 in the above list were used in photographing the total phase—the first by Mr. Willard, and the second by Mr. Mahony. As in 1869, the photographs were taken in the principal foci of the object-glasses of both instruments. Guided by my experience in observing the eclipse of 1869, at Shelbyville, I had arranged the cameras for these telescopes in such a way that at the instant of totality the slides which were used for making instantaneous exposures of the plates for partial phases might be drawn out and thrown aside, so that there might be no danger of cutting off any part of the corona. This apparatus, although rough in appearance, answered its purpose admirably in 1869. But on this occasion I was induced to allow another to be substituted for it, shortly before the eclipse. The new contrivance seemed very ingenious and unobjectionable, and not having sufficient time to consider it attentively, I supposed that it would answer as well as the old one. Unfortunately the slide of this apparatus could not be removed, and the opening in it was small, so that, in the best of the two photographs taken, part of the outer corona was lost, although the whole of the inner corona seems to have been secured. Its outline is distinctly seen, surrounded by the fainter light which alone was limited by the diaphragm.

The triggers which released the slide in the apparatus which was used required a light for their successful management, and the accidental blowing out of this light caused some confusion in the photographic work, which may have resulted in additional defects in the pictures obtained.

The picture of the corona, plate 12, taken at Shelbyville in 1869, represented, in my opinion, all the bright part of the corona, and its true form. From the rapidity with which the intensity of the light diminishes toward the borders, what lies outside of this must be very faint. The extent of the visible corona has been variously estimated by different observers, in all eclipses of the sun. It seems to depend in no unimportant degree on the clearness of the atmosphere. This is especially noticeable in the accounts of the eclipse of 1851, given in Vol. XXI of the Memoirs of the Royal Astronomical Society. In these accounts the estimate of the breadth of the corona is less when the sky is represented as clear; so that in some instances it is estimated but little larger than it appears in photographs.

My plan was to take three photographs of the corona with the 6-inch and one only with the 8-inch telescope; that is, to leave the plate exposed in the latter during nearly the whole of the total phase, hoping that this large aperture and long exposure would secure the outer faint light, while the bright parts of the corona would be distinctly represented in the photographs made with the smaller instrument. Everything was in readiness for carrying out this plan, but the discouraging aspect of the weather on the day of the eclipse, which is sufficiently described in the reports of my colleagues, made it hopeless to attempt so much. Accordingly, instead of giving directions for a certain number of exposures of specific duration, I simply directed the photographers to watch their opportunity, and to use their own judgment as to the time of exposure, guided by the intensity of the light, modified, as it most likely would be, by the clouds. One good picture was, if possible, to be obtained with each telescope. The photographs actually taken during totality are represented by the engravings, plates 13 and 2, the first being taken by Mr. Willard and the second by Mr. Mahony. Several positives on glass were taken by Mr. Willard immediately after the eclipse, some of which were left in England, and have probably served as the originals of the prints that have appeared in several publications on this subject. These positives were taken from the first photograph, plate 13; the second was regarded by Mr. Willard as a failure, and I did not know of its existence until after my return home. I do not know how to account for its appearance. Mr. Willard attributes it to the shaking of the telescope by the wind. Inasmuch as the outer edge of the light fell clearly inside of the mark of the diaphragm in the plate, I thought it worth while to have an engraving made from this photograph, if only to show how far from the image of the moon the plate had been affected by light from the corona, the aperture having been 8 inches and the time of exposure, as nearly as I can ascertain, one minute and a half.

It is not easy to represent correctly in engravings the appearance of the original negatives. It has been found impossible to print the outer faint lights directly from the negative, in which, however, they can plainly be seen. The method adopted in the case of plate 2, from the photograph made with the 8-inch telescope, has been to make a drawing from the projection of the negative upon a screen by means of a powerful calcium light. The drawing is intended correctly to exhibit the extent and form of the different masses of light which it depicts, but not their relative brightness. None of the photographs of the total phase taken under my direction, either in 1869 or in 1870, can be fully represented by photographic printing. In plate 13 there is seen an inner corona, resembling in form and dimensions the corona of plate 12, from the Shelbyville photograph. In the positives on glass no trace of this is seen when the picture is held between the eye and the light, but it becomes very distinct when the picture is placed on a dark surface and examined by reflected light. The same thing is apparent in a less degree in the photograph of 1869. In this case the prominences, which are very distinct in the negative and correctly represented in the engraving, are not shown at all in photographic prints. The same is true of the internal structure of the corona. In the original negative this has a fibrous or woolly appearance, which is lost in copying by photography, and is not shown in plate 12, which is a copy on steel of a photograph, with the prominences added by a tint-stone.

The position angles on the margin of these engravings are counted from the north pole of the sun through the east. They were obtained in the following manner: The camera remained undisturbed from the beginning to the end of the eclipse; the edges of the glass plates were straight and parallel. Hence, by placing the plate containing the total phase between two plates showing partial phases before and after totality, I was enabled to determine the position from the line of cusps with all the accuracy attainable in a diagram of the proportions of these plates.

In the spring of 1870 I received from Father A. Secchi an engraved copy of a photograph of the eclipse of 1860, taken by him in Spain; and one of the first points in it which attracted my attention was the remarkable resemblance between the form of the corona therein depicted and that shown in the photograph taken in 1869. The photograph of 1870 was subsequently found to resemble each of the others. This resemblance extends to the principal depressions in the corona as well as to its general arrangement about the sun's axis. I communicated these facts at the time to the American Academy of Arts and Sciences, and illustrated them by the drawing, plate 3, in which the three pictures are reduced to the same scale and placed in the same position, with the north pole uppermost.

Besides the general work incident to the organization and equipment of the expedition, and the care of securing the conditions which offered the best chance of success in all the observations undertaken, I had laid out for myself the special occupation of endeavoring to ascertain the nature of that fainter portion of the corona which lies outside the limits of the best photographs, and concerning which there have been such conflicting accounts and opinions. I had no doubt that the brighter parts of the corona would receive from other observers more than their due share of attention; and I felt confident that sooner or later the principal facts relating to their constitution would be settled without the aid of total eclipses.

I undertook simply to get answers to these two questions: What bright lines are visible in the spectrum of this fainter light, and whether or not any dark lines are to be seen in it. My previous experience in Kentucky had made me aware of the serious loss of time, as well as of the confusion and liability to error, inseparable from any method of fixing the positions of lines in the spectrum during totality by means of a scale to be read and recorded at the time of observation. It seemed to me very important that there should be some means of making a permanent record of the place of a line at the instant when it was seen, without loss of time or distraction of attention. This record could then be measured and studied at leisure. These considerations led me to an invention which I thought well adapted to its purpose, and likely to be useful in spectroscopes of any construction. It consists in rigidly attaching a point or cutting tool to that part of the spectroscope which is moved to effect a pointing on a given line of the spectrum, in such a way that it may be pressed upon a plate suitable to receive the record when the telescope is directed to the spectrum line to be recorded. Any number of lines from a given spectrum may thus be registered, and by sliding the plate on which the record is made in a direction normal to that of the motion given, by changing the pointing of the spectroscope to the recording tool any number of spectra may be registered side by side for ready comparison. The first and the simplest method that would occur to any one would be to use a point to prick a hole in some soft substance. But being afraid that the dots so produced might be confounded with small spots or accidental indentations on the plate, and that this would lead to confusion and uncertainty in identifying the record, I thought it safer to give the point a sliding motion after it touched the plate, so as to make a mark similar to those on the limbs of graduated instruments, about which there could be no mistake. The manner in which this was done is illustrated in plate 19 and plate 11, Fig. 3. The instrument shown in plate 19 was completed and exhibited to the American Academy in October, 1870.

In Professor Young's spectroscope, I attached the recording tool to the prisms. In all these instruments, I dispensed with clamps and used double-threaded tangent screws to give rapid motion in pointing without danger of slipping when the record should be made. I also applied to the spectroscopes small reflectors by which the observer could see the image of the sun on the slit without removing his eye from the telescope.

My method of using this mechanical recording apparatus was first to register some standard lines of the solar spectrum or of the spectrum of some well-known substance; then to slide the plate and to register the lines to be determined by the side of the first series. The plate is then to be put under a microscope and the places of the lines determined with a micrometer. For general use in spectroscopes I proposed to rule a scale of standard lines of the solar spectrum, and to interpolate from this any desired scale, one of wave lengths, for instance, or that of Kirchhoff. This scale should then be permanently attached to the spectroscope in such a way that the place of an observed line in the adopted scale may be read off at a glance.

The telescope which I used at Jerez was an equatorial of $5\frac{1}{4}$ inches aperture, and about 7 feet focal length, made by Alvan Clark; it was mounted without clock-work, and had attached to it, as a finder, a very excellent telescope of $2\frac{1}{2}$ inches aperture, and a power of about 40, known as the Quincy comet-seeker. These instruments are Nos. 1 and 7 of the list given above, and the spectroscope used was No. 10 of the same list.

The cross-wires of the finder were carefully adjusted the evening before the eclipse, so that when the finder was pointed on a star its spectrum would appear in the spectroscope. I adjusted the width of the slit by faint clouds or patches of blue sky, so that if dark lines were present they could not escape me, and a faint continuous spectrum might not be cut off. Mr. Alvan G. Clark, whose skill in everything pertaining to a telescope insured careful and judicious management of the instrument, was stationed at the finder to direct the telescope to the parts of the corona which were to be examined, and at the same time to observe incidentally general phenomena. Mr. Clark took his place at the finder just before the beginning of the total phase. On the instant of totality, he directed the telescope, according to my instructions, upon the faint part of the corona, about 12′ from the edge of the moon, and seized every opportunity offered by openings among the clouds previous to the re-appearance of the sun to obtain for me a view of the coronal light unmixed with reflected rays. He several times reported, "Now it is clear here;" and on looking into the spectroscope I saw a continuous spectrum, not very faint, with four bright lines. The appearance remained unaltered, except in brightness, as Mr. Clark moved the instrument from point to point of the corona. I carefully registered these lines on the silver plate, and then requested Mr. Clark to move the instrument away from the sun until the lines should disappear. As he did so, I tried to note the order of disappearance of the lines. They all disappeared nearly at the same time, having previously faded out together, one of them, which proves to be that known as 1474, seeming to be somewhat more persistent than the rest. When the lines had all vanished, Mr. Clark reported that the instrument was then pointed about 25′ from the sun.

The double-threaded screw which moved the telescope of my spectroscope enabled me to sweep rapidly from one end of the spectrum to the other. During my examination of the corona I looked carefully for dark lines, and saw none. I examined critically the whole region above F, and saw nothing but a continuous spectrum. I looked for lines here because I had seen broad lines near H in 1869.

Some standard solar lines had been registered on the silver plate before the total phase, and the plate had been moved as has been described to receive the lines of the corona. After the total phase, the principal lines of the solar spectrum, as high as F, were again registered.

The cross-wires in the spectroscope had been made very coarse for fear that it would be difficult to see them. No such difficulty was found, and with finer wires the precision of the pointings upon the lines might probably have been somewhat increased. But no considerable error can have occurred, since the dark lines registered before the total phase agree well with those registered after it, and the same lines ruled on mica at the present time can be superposed on those recorded upon the plate, which have in fact thus been identified.

An examination of the silver plate shows that the coronal lines observed were C, a line near D, 1474, and F. C and F agree exactly with the dark lines. The line near D is less refrangible than the sodium line D, by a difference greater than I supposed the error of observation could be. Line 1474 is ruled a little more refrangible than Kirchhoff's line, perhaps not more than can be attributed to an error of observation under the circumstances.

The last adjustments of my own instrument were completed at 11 o'clock on the morning of the 21st, and at that time the sky was perfectly clear, and there was every reason to hope for fair weather on the day of the eclipse. Our preparations were complete; nothing that could be thought of had been neglected; all of the party were experienced observers; each was familiar with his instrument, and with one or two exceptions had been out to observe the eclipse of 1869. At 4 a. m. on December 22, I found the heavens nearly covered with clouds, and every appearance of an approaching storm. From that time to the very instant of totality the prospect was disheartening; and while we have to regret that much of the value of our work was lost or impaired by the clouds, it is even now a matter of surprise to me, when I recall all the circumstances, that so much was done and that so many things were seen.

JOSEPH WINLOCK.

DARTMOUTH COLLEGE,
*Hanover, New Hampshire, May 26, 1871.*

SIR: I have the honor to submit the following report of my observations of the eclipse of December 22, 1870, made at Jerez de la Frontera, in Spain, as a member of the party under your charge.

By the liberality of the trustees of Dartmouth College I was granted leave of absence for four months and authorized to take with me any astronomical or physical apparatus belonging to the institution, the mere expenses of transportation and insurance being paid from the Government appropriation.

LIST OF INSTRUMENTS LOANED BY DARTMOUTH COLLEGE.

The instruments furnished to the expedition by the college were as follows:

1. An equatorial telescope (by Merz & Sons) of $2^{m}.64$ focal length and $0^{m}.162$ aperture, provided with clock-work and the usual accessories.
2. A spectroscope, by Clark & Sons, specially fitted to the above-named telescope, and having the dispersive power of thirteen prisms of 55° each. Its telescope and collimator have each an aperture of $23^{mm}$ and a focal length of $177^{mm}$. It is the same instrument described in the Journal of the Franklin Institute for November, 1870, where it is figured. This instrument was provided (at the expense of the Government appropriation) with Professor Winlock's beautiful arrangement for registering the position of spectral lines.
3. A "comet-seeker," by Merz & Sons, of $95^{mm}$ aperture and $760^{mm}$ focal length, equatorially mounted with slow motions. This was fitted with a solar eye-piece for observing contacts, and with an arrangement for tracing the image of the corona upon a ground-glass screen during totality.
4. The telescope, collimator, and five prisms of a large nine-prism spectroscope. The object-glasses have an aperture of $57^{mm}$ and a focal length of about $440^{mm}$. The prisms are of corresponding dimensions, with a refracting angle of 45° each.
5. An ordinary single-prism spectroscope by Clark.
6. A so-called meteor-spectroscope (direct vision) by Browning.
7. A small induction-coil, with galvanic battery and set of Geissler tubes.
8. A collection of Nicols prisms, crystals, and colored glasses.
9. An excellent pocket-chronometer by Barwise.
10. Two spy-glasses and a binocular field-glass.
11. A combined compass and clinometer.

Of these instruments, Nos. 1, 2, 7, and 9 were used by myself. No. 3 was employed by Mr. Dean in observing the first contact, and afterward by Mr. Norman in sketching the corona. The telescope, collimator, and two prisms of No. 4 were combined into an instrument which was used by Mr. Abbay; the Nicol's prisms and crystals were loaned to Professor Pickering, and the other instruments to various amateurs who offered us their aid in sketching or other forms of observation.

Leaving Hanover on October 31, I sailed from New York for Liverpool on November 3, (in company with a large number of our party,) and finally arrived at Jerez, via Southampton, Gibraltar, and Cadiz, on December 9, one day previous to the time appointed, but still the last member of the party to come upon the ground.

My instruments had been carefully packed at Hanover and sent to Cambridge, whence they had been forwarded with the other instruments of the expedition. I found them at Jerez awaiting my arrival, and on opening the boxes everything came out in good order with a few trifling exceptions.

As the observatory for the meridian-instruments and the arrangements for the photographic corps had first to be attended to, it was not until December 16 that my instrument was mounted, and it was the 20th before I had it well adjusted, the weather having been unfavorable most of the time.

It was placed under a large tent, kindly loaned to the expedition by the Jerez Cricket Club, very near the instrument of Professor Winlock, but at a distance of 30 meters or more from the rest of the party.

INSTRUMENTS.

For the observation of the eclipse I used the large equatorial previously mentioned, armed with the Clark spectroscope. The telescope is a very good one. The spherical aberration is very nicely corrected, but the correction for color is somewhat overdone, (as is the case with most of the Munich glasses,) the focus for the C line being about $15^{mm}$ nearer to the object-glass than that for G. This is, however, of comparatively little importance in spectroscopic observation.

The driving-clock perhaps deserves something more than a passing notice, on account of certain peculiar features which I believe are new.

It is one of the small machines such as Merz & Son have been accustomed to furnish with their instruments, regulated by Fraunhofer's centrifugal friction governor, and although it went very fairly when everything was new and in perfect order, it has far too little power to drive so large an instrument under ordinary conditions. But I have succeeded in bringing it to satisfactory performance by the following simple modification: The axis of the driving-screw revolves (when the clock-work is running accurately) once in 7 seconds. Upon this axis is secured a wheel with seven teeth like those of a scape-wheel. By adjusting the governor so that it will, when left to itself, run a little too fast, and then slightly checking this wheel every second, it is evidently possible to secure a very close approximation to uniform motion, the principle being precisely the same as in Bond's spring-governor. This necessary periodical check is obtained thus: The armature of an electro-magnet is attached to a lever which carries at its extremity a piece of watch-spring about $25^{mm}$ long. While the current is flowing through the coils of the magnet, this spring is pushed down between the teeth of the scape-wheel, and would stop the machine entirely if allowed to remain there; but the magnet being connected with a clock which breaks the circuit every second, the spring is then drawn back for an instant and the tooth allowed to pass, having been merely checked a little, just enough to prevent the clock-work from running ahead. Fig. 2 is designed to illustrate the arrangement.

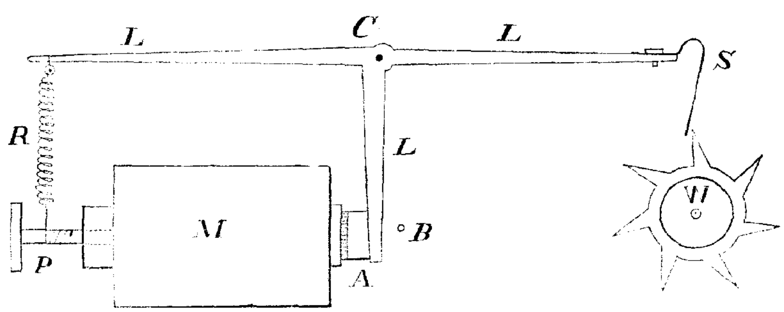


Fig. 2. Apparatus for controlling the driving-clock.

W, scape-wheel with 7 teeth; S, check-spring; C, center of motion of lever L L.; B, banking pin; A, armature faced with brass; M, electro-magnet; P, winding-pin, controlling the tension of the adjusting spring R.

In the observatory the magnet is connected with the solar clock if the telescope is to follow the motion of the sun; with the sidereal if a star is under observation. But having no clock at Jerez which could be conveniently used for this purpose, I had recourse to an expedient suggested by Professor Winlock, which answered admirably. A seconds pendulum, with a break-circuit attachment, but without other appendages, was mounted upon the telescope pier, and kept in motion by an occasional touch of the finger. It would swing without requiring any attention for about ten minutes at a time, and whenever the arc of vibration was too much reduced, the peculiar sound of the magnet at once attracted notice and called for the needed impulse.

I am confident that the plan of connecting the driving clock of an equatorial with the standard clock of the observatory, in some such way as I have described, will be found exceedingly satisfactory by any one who may try it—a vast saving of annoyance and vexation by rendering unnecessary the continual adjustments which are otherwise required by slight changes of balance in the instrument, variations of temperature, &c. If the performance of the driving-clock before being thus controlled be simply tolerable, then when connected with the standard clock it becomes as perfect as the clock itself, provided, of course, that the polar axis is accurately adjusted.

For the purpose of mounting the equatorial, a large post about 25 centimeters square was set into the ground to the depth of a meter, and the top was sawed off at an angle a little greater than the latitude of the place, the inclination being roughly measured by the clinometer.

Upon the top of the post was secured, by a single strong bolt near the upper extremity of the slope, a piece of plank about 20 centimeters wide by 760 in length; to this was firmly bolted the bed-plate of the polar axis. The plank being thus fastened to the post at one point only, it was possible to swing it around enough for the needed azimuthal adjustment, and by driving wedges between the top of the post and the plank, slight changes of the inclination of the polar axis could be readily effected; at the same time the weight of the telescope and its mountings was abundantly sufficient to keep everything in place unless purposely disturbed.

The spectroscope was attached to the telescope by a stiff tube of hard brass about 32 millimeters in diameter. This is clamped to the tail-piece of the telescope by a pair of strong rings; and in a similar manner the frame of the spectroscope is secured to the rod by two clamp-screws, so that by simply loosening these the spectroscope may be brought nearer to or removed farther from the telescope in order to bring the slit to the exact focus of the particular rays of the spectrum under examination.

To facilitate this exceedingly important adjustment, lines were marked upon the rod corresponding to C, $D_3$, *b*, F, and G.

Sometimes, instead of using this arrangement, the spectroscope is slid to a little greater distance and the image is thrown up by a concave lens of long focus; this enlarges the image somewhat, and by sliding the lens slightly, in or out, a most accurate adjustment of focus is attainable. But a little loss of light and injury to the definition from the action of this supplementary lens makes the former method preferable as a general rule.

A small piece of card with an orifice in its center was fastened over the slit, and no other finder was necessary, as even during the totality the image thrown upon the card was abundantly bright to enable me to point to any desired portion of the corona with perfect certainty.

A little mirror was attached to the brass carrying-rod, and so arranged that with one eye I could see in it the card and the image upon it, while the other was at the eye-piece of the spectroscope.

As has been mentioned before, the instrument was provided with the beautiful arrangement of Professor Winlock, which, by a mere touch of the finger, records permanently upon a silver plate the exact location of any line that may be upon the cross-wires.

OBSERVATIONS.

The 21st of December, the day preceding the eclipse, was perfectly clear, and I took advantage of it to complete the adjustments of my instrument, and to examine the circumference of the sun for prominences. There were no very large ones, but several that were very brilliant and very active. One on the northwest limb was particularly so, and its spectrum contained not only all the bright lines I had ever seen before, but some new ones. I noticed especially an iron line below C, the reversal of 655 Kirchhoff, and the three chromium lines at 1601, 1605, and 1607 of the same scale. The red line has been seen before, but only rarely; on this occasion, however, it was so bright that I showed it without difficulty to several of the bystanders. The chromium lines are, I believe, entirely new.

It was my intention to examine the whole circumference of the sun on the morning of the eclipse, and to map down the different protuberances. This was prevented by the clouds, for during the night the sky had become overcast, so that the prospect was exceedingly gloomy for us. We made all our preparations, however, and a little while before the beginning of the eclipse the clouds cleared away somewhat, and I was in hopes that I might be able to use the spectroscope in observing the first contact.

But the chromosphere lines were only occasionally and faintly visible through the haze, (which even when thinnest was always sufficient to produce a well-defined halo of 22° radius,) and I was, therefore, unable to make a satisfactory observation. I had, however, a momentary glimpse of the moon's limb on the chromosphere, and announced her approach some ten seconds before Mr. Alvan G. Clark, who was standing very near, using the large finder of Professor Winlock's telescope, perceived the contact. His observation was made at $10^h\ 25^m\ 45^s \pm 2$ by my chronometer, which I had previously set by the standard chronometer in Mr. Dean's observatory, allowing for the error of the standard at the time of comparison, as given by Mr. Dean. I suppose that taking into account everything, the error of my chronometer could hardly have been more than from 3 to 5 tenths of a second at the time of Mr. Clark's observation; but as I looked at its face only *after* Mr. Clark spoke, taking my eye from the eye-piece of the spectroscope for the purpose, the *error* of *noting* may easily amount to the $\pm\ 2^s$ indicated.

Immediately after the contact, I took off three of the prisms from the spectroscope, reducing its dispersive power from 13 prisms to 7, the largest number which could be used with the registering apparatus. I was not able, however, to adjust the instrument and cut the comparison spectrum upon the register plate, until within a few minutes of totality, as we could only catch momentary and unsatisfactory glimpses of the sun between the thickening clouds. These seemed to grow continually denser and more numerous, so that we were all oppressed with apprehensions of total failure. But a few minutes before totality, a rift of blue appeared in the west, and we hailed it as affording a gleam of hope. Slowly it drifted along, directing its course straight toward the sun—now reduced to a narrow crescent. At last it reached it; in a moment more the moon had completed the event, and there, in clear air, between the dense masses of heavy clouds, hung the beautiful spectacle.

I had previously laid down for myself the following programme:

1st. Observation of 1474, and ascertainment of the distance to which it could be traced from the sun's limb.

2d. Examination of the corona spectrum for other bright lines, as well as for dark lines, and the registry of any that might be found.

3d. Examination of the extension of the chromosphere lines outward and inward upon the disk of the moon.

4th. Examination of the spectrum of a prominence, if time permitted, in order to find lines invisible except during an eclipse.

In accordance with the programme, as soon as the sun came out into the clear sky, I had adjusted the slit of the spectroscope accurately tangential to the limb of the sun at the point where the last ray would vanish, and brought the 1474 line to the cross-wires. It was already plainly bright, the atmospheric glare being so much reduced as to make it perfectly easy to see.

The lines of *b* were also distinctly reversed, as were several of the iron lines near E, and I even thought that I could see the three chromium lines which I had found the day before.

Very soon, as the crescent grew narrower, they shone out unmistakably, and all the other lines I have mentioned became continually more conspicuous, while the dark lines of the spectrum and the spectrum itself gradually faded away; until all at once, as suddenly as a bursting rocket shoots out its stars, the whole field of view was filled with bright lines more numerous than one could count.

The phenomenon was so sudden, so unexpected,* and so wonderfully beautiful as to force an

* It was unexpected simply because it had not been seen in 1868 and 1869. In 1869, having been led to expect something of the kind by Father Secchi's report of a layer close to the sun's surface, giving a continuous spectrum, I looked for it very carefully, but failed to see it, so that on this occasion I was wholly unprepared.

I now suppose that my previous failure was due to my having worked with a *radial* slit; in this case the lines would be so short (from $0''.5$ to $1''.5$) that they might easily escape observation.

It is of course possible that the phenomenon may have been caused by some unusual disturbance in the solar atmosphere, (such as Mr. Lockyer has already seen on one occasion,) by which the denser vapors were carried up into the chromosphere.

If, however, as seems much more probable, the layer always exists, and is the true birthplace of the Fraunhofer lines, it is quite possible that it may be detected even without an eclipse by observations made at some elevated station, such, for instance, as Sherman, at the summit of the Pacific Railroad.

involuntary exclamation. Gently and yet very rapidly they faded away, until to within about 2 seconds, as nearly as I can estimate, they had vanished, and there remained only the few lines I had observed at first.

Of course it would be very rash on the strength of such a glimpse to assert with positiveness that these innumerable lines corresponded exactly with the dark lines of the spectrum which they replaced; but I feel pretty fairly confident that such was the case.

The grouping of the lines seemed perfectly familiar and so did the general appearance of the spectrum, except that the lines which had been visible before the totality were relatively far too conspicuous.

Mr. Pye, as will appear from his report, also saw the same thing for an instant.*

As soon as this bright line spectrum had vanished, I gently pressed against the side of the telescope tube and forced the slit away from the image of the sun toward the east. All the lines in the field (the four lines of *b*, the three chromium lines, and two or three iron lines near E) immediately disappeared except 1474, while this continued bright, though of course growing fainter as the distance from the sun increased; but by opening the slit somewhat I could trace it to a distance from the limb of more than the sun's radius, or about 16′, as determined by a glance at the card attached to the spectroscope, upon which the image of the eclipse was distinctly and beautifully visible. Light flocculi of cloud were continually and swiftly drifting over it.

By touching the tangent screw the C and $D_3$ lines were then brought into the field of view and their behavior examined. So long as the slit was in the chromosphere they were dazzlingly bright; but as soon as the slit was removed from this they became *suddenly* fainter, although I could trace them to a distance of 4 or 5 minutes outside of the sun and even upon the disk of the moon. F was then tried, and behaved similarly, except that being less brilliant I could not follow it so far. I have no doubt, however, that their extension beyond the limits of the chromosphere was due to reflection from the haze and flocculi of cloud above mentioned, as I saw nothing of the sort in 1869, in a clear sky.

A faint, continuous spectrum, much brighter near the sun, always formed a background for the bright lines. I saw no traces of dark lines in it, though I looked for them carefully.

Besides 1474, no other lines were seen which behaved in a similar manner or could possibly be due to the corona.†

About a minute had been consumed thus far, and I determined now to take one deliberate look at the eclipse, and did so for about 10 seconds. What I saw certainly appeared to me very different from the impressions of the eclipse of 1869. Then, under an absolutely clear sky, the corona seemed to me somewhat smaller and more sharply defined than now; far more brilliant and more beautiful then, but striated only with fine lines without any heavy markings. (Some of the observers, however, who were in Kentucky in 1869, make a very different comparison of the two eclipses.) On this occasion the corona appeared very indefinite in its outline; roughly a square with its diagonals at an angle of about 45° with the vertical, (and with the ecliptic also, since the eclipse took place at noon, and the sun was near the solstice,) and having the sun somewhat out of

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* Father Secchi, in a note published in No. 1834 of the Astronomische Nachrichten, reports something perhaps similar. He writes:

"Une minute ou deux après la totalité je fixai le spectroscope à la grande telescope de Cauchoix avec laquelle nous avions fait les photographies et je visai à l'extrémité des cornes de la phase; le spectre était très discontinu; je souçonnai d'abord quelque dérangement mais ce n'était rien; la discontinuité était très grande et visible, malgré que la fente fusse assez large, car elle était destinée à régarder la forme des protubérances et à en relever la différence avec celle que j'avais observée tout à l'heure.

"Quelques minutes après les cornes s'étaient élargies cette discontinuité disparut. Cette observation me parait très importante et elle nous ouvre un nouvel horizon sur la constitution de la bord du soleil. M. Mobile a terra nova a fait aussi une observation semblable."

† In the same letter of Father Secchi, from which a quotation has been already made, he writes:

"Mon collègue le P. P. Denza, directeur de l'observatoire de Moncalieri, observa avec un spectroscope que j'avais convenablement disposé, deux raies brillantes dans la couronne, une près de l'E de Fraunhofer, l'autre au milieu entre le vert et la jaune. Faute de temps on ne pût pas mieux fixer la position."

The one near E was evidently 1474, and it would seem pretty likely that the other "half way between the green and the yellow" might be one of the two faint lines which I saw in 1869, and *doubtfully* reported as corona lines.

the center. But I was most struck by several straight dark streaks apparently related to the protuberances, which extended out from the sun through the corona and into the sky beyond to a distance fully equal to the sun's diameter.

Mr. Gilman's picture of the eclipse of 1869, (published in the report of the Naval Observatory party,) gives a better idea of them than anything else I have ever seen, although I confess that hitherto I had thought it greatly exaggerated. I did not see so great a number of rays as he has shown in that figure, but those I did see, five or six in number, three of which were especially conspicuous, are accurately represented by his sketch. The darkness was not so great as in 1869. I had no difficulty whatever in reading the seconds dial of my pocket-chronometer. Undoubtedly the obscurity was rendered less effective by the gloom that had preceded it caused by the heavy clouds.

Resuming the spectroscope, I examined hastily the other portions of the sun's circumference to determine the extent of the corona as shown by the 1474 line, and with the following results: On the west limb I traced it to a distance of 13′, on the north, 12′, on the south, 10′. A few moments still remaining, I took a hurried glance at the spectrum of the chromosphere on the western edge in order to look for new lines, but found none. I saw the following: C, $D_1$, $D_2$, $D_3$, 1474, 1515, 1519, 1601, 1605, 1607, $b_1$, $b_2$, $b_3$, $b_4$, 1990, 2001, 2003, 2031, F, and 2185—twenty in all. The examination was not extended below C nor above 2185, for while I was looking at the last mentioned line, and before I could bring it to the center of the field, the sun emerged. I was somewhat surprised and disappointed at not finding any new lines; perhaps a closer scrutiny with a somewhat widened slit might have been more successful.

I ought to add that the positions of the lines above *b* were determined only by my general knowledge of that portion of the spectrum, and the fact that the lines named are often observed there. I did not have time to bring them accurately to the cross-hairs and cut them upon the register-plate. I hurried the observation in order to catch, if possible, at the close of the eclipse, the same reversal of the Fraunhofer lines which I had seen at the beginning, but I was not quick enough, and as the slit was not in the proper position, I did not see it.

The sun had hardly re-appeared from behind the moon when the clouds again covered him, and we saw no more sunshine until evening, when the sky cleared off beautifully from the west after a heavy storm of wind and rain, which seriously troubled us in dismounting and repacking our instruments.

### OBSERVATIONS OF MR. ABBAY.

In 1869 Professor Pickering observed the eclipse with an ordinary chemical spectroscope of one prism, unattached to a telescope. In this way he obtained a spectrum due to the total light from the whole mass of luminosity surrounding the sun within a distance of 3 or 4 degrees. He reported a continuous spectrum, in which, however, there were several bright lines, one in the red near C, another near D, and a third near E, brighter than either of the others. I never doubted that this brightest line was 1474, but as Professor Pickering had only been able to make a rough estimate of its position, Mr. Lockyer and some others were disposed to dispute this conclusion and consider it to be F. To settle this question, and because this method of observation appeared to promise results of value when combined with those obtained by the telescopic spectroscopes, it was determined to repeat the observations on this occasion.

As, however, we had no spare observer, Mr. Abbay, of Wadham College, Oxford, member of the English party under the charge of Rev. S. J. Perry, which was located near us at Puerto Santa Maria, kindly volunteered, on the suggestion of Mr. Lockyer, to join us temporarily, and use an instrument compiled for the occasion out of the collimator, telescope, and two prisms of the large spectroscope belonging to Dartmouth College. The collimator and prisms were firmly attached in the proper position to a board, and the viewing-telescope was mounted upon an arm turning on a pivot under the center of the nearest prism.

This arm was moved by a tangent screw, and an arrangement was fitted to it with which the exact position of the telescope at any moment could be registered by the puncture of a needle-point upon a piece of card, a rough, but effective imitation of the more elegant registering-apparatus attached to the other instruments.

The board to which the prisms were fastened was itself secured by a screw at its center of gravity to the extremity of a horizontal bar so that it could move freely in a vertical plane. The bar, counterpoised at the other end, turned upon a vertical pivot on the top of a post firmly planted in the ground. Thus the collimator could be directed to any portion of the sky, and by means of a shadow pointed accurately upon the sun.

The slit was provided with a comparison prism, and Mr. Abbay brought with him a small induction coil and a Geissler tube, which gave the combined spectra of hydrogen, sodium, magnesium, mercury, and iron.

This tube, prepared for the purpose in Mr. Lockyer's laboratory, was first exhausted by a mercurial pump, which always leaves some of the vapor of mercury in the partial vacuum so formed, and then filled with rarefied hydrogen. One of its electrodes was of iron encrusted with a sodium salt, the other of magnesium. It was permanently attached to the instrument in such a position with reference to the comparison prism that its spectrum could at any moment be brought into view by simply starting the induction coil. No better reference scale could be desired for determining the position of any lines that might be observed.

I simply annex the report of Mr. Abbay, without attempting to account for the very curious circumstance that he saw the C and $D_3$ lines (I have no doubt that the line he called D was really $D_3$) only at the beginning of the totality, but afterward only 1474 and F; while Mr. Pye (and Professor Pickering, in 1869) observed no such change in the character of the spectrum.

*Report of Mr. Abbay.*

OXFORD, *January* 24, 1871.

MY DEAR PROFESSOR YOUNG: I am rather ashamed to be so late in sending you my report of the work done with the chemical spectroscope you so kindly lent me.

The field of view was about 7°, so that the light passing through the prisms was composed of prominence, coronal, and general light extending to a distance of 7 or 8 diameters on each side of the sun. A short time before totality began, I arranged the slit so that the D lines just appeared as a single thick line, this being the narrowest slit which it seemed safe to attempt to use, and I had determined to narrow the slit considerably if the bright lines appeared as bands on a continuous spectrum. At $11^h\ 44^m$ Jerez time, I noticed the B line extremely black. As totality approached, the dark Fraunhofer lines slowly disappeared, leaving a dull spectrum, which also faded away immediately before three bright lines, (C, D, and F,) identified by means of the vacuum tube, made their appearance.

These three lines came into view within 2 or 3 seconds after the shout announced that totality had begun, and they remained about 8 or 10 seconds. When they disappeared, two very bright sharp lines were seen, one coincident with the bright F line given by the vacuum tube, the other less refrangible than *b*. After some trouble, I succeeded in placing the cross-wires on this bright line, and determined not to move the telescope during the rest of totality.

No other line appeared, although the C line of the vacuum tube was in the field on the one side and the F line on the other. I saw no continuous spectrum; the lines were bright on a dark ground. The F line was a little less bright than the other.

On the re-appearance of the dark lines after totality, I found that the cross-wires were on the vacant space between the lines 1464 and 1494 of Kirchhoff's scale. This measurement was as accurate as it was possible to make with the instrument, so I cannot say with certainty that the bright line seen was absolutely coincident with the 1474 line.

In order to get an idea of the dispersive power of the prisms, I tested the instrument by means of the light of the dull heavy clouds which obscured everything after totality, and found that I could not separate the D lines; but I was able to obtain four thick lines between E and *b*. I also saw 1464 and 1494 as single thick lines.

At the end of totality, I noticed no re-appearance of the bright lines C and D, nor do I remember at what moment the continuous spectrum again came into view.

At about the middle of totality, I looked up for a second or two at the corona. It appeared distinctly and unevenly radiated. The light was pearly white, apparently of about the intensity of the full moon, and the shadows cast by certain parts of the instrument seemed as deep as those of a bright moonlight night.

I think the dark Fraunhofer lines disappeared through want of light, and I do not believe it possible to prove their non-existence in the corona on account of that want of light.

I believe, but this is rather an opinion than the result of experiment, that the real corona is small compared with what we see, and that it is apparently magnified partly by irradiation and partly by reflection at an angle nearly 180° in the earth's atmosphere, so that under favorable circumstances bright lines may be obtained at an enormous distance from the sun's limb.

I am very glad that my results have confirmed your previous observation in 1869, and thanking you again for the use of your instrument,

I am, ever sincerely, yours,

R. ABBAY.

OBSERVATIONS BY MR. PYE.

Mr. Walter Pye, a young English gentleman, who was spending the winter in Jerez for the benefit of his health, had kindly offered his services as an assistant in any observations that might be desirable. As he had had some experience in spectrum analysis, and as there still remained another spectroscope unprovided with an observer, this was assigned to him.

The instrument was a star spectroscope belonging to the observatory of Harvard College, with a single prism of extra dense yellow glass having a refracting angle of 60°. The telescope and collimator had each an aperture of $23^{mm}$ and a focal length of about $180^{mm}$. Its dispersive power was such that it showed without much difficulty the four lines of *b* distinct and separate. It was provided with the registering apparatus of Professor Winlock. This instrument was mounted on the same general plan as Mr. Abbay's; but to secure more light, at the same time allowing the slit to receive its illumination from the whole coronal region, I employed the following device: A small telescope, magnifying about $2\frac{1}{2}$ times, with a field of about 7°, was carefully adjusted for distinct *distant* vision of a remote object, *i. e.* so that the rays from any portion of the object after emerging from the eye-piece should be exactly parallel to each other. This being placed in front of the spectroscope its effect is, not to form an image on the slit and thus restrict the observed spectrum to that of some particular portion of the coronal region, but simply to magnify the angular area from which the light proceeds to a diameter of about 4°, and thus to increase the light nearly six-fold. The contrivance succeeded perfectly, so that although the intrument was much smaller than Mr. Abbay's, I think it was fully its match in power and efficiency. A little more care in pointing was requisite on account of the condensing telescope, as we called it. To facilitate the operation, a thin piece of metal, with a round orifice in it of 2 or 3 millimeters diameter, was attached to the frame-work, and at a distance of about 30 centimeters a card was placed with a circle marked upon it. The instrument was directed by bringing the spot of light formed by the orifice into the center of this circle.

I append Mr. Pye's report, and it will be seen that his results are in perfect accordance with those obtained by Professor Pickering in 1869.

*Report of Observation.*

At the first instant of totality a great number of bright lines were seen, the effect being as if all the dark lines of the spectrum were converted into bright ones; these lasted only for an instant, and were seen with the slit nearly closed.

Then with a wide slit the following lines were observed: (1) C, very bright; (2) a bright line near D, probably $D_3$; (3) No. 1474—by far the brightest of all—peculiarly sharp and distinct; (4) F, the faintest, but sufficiently distinct.

A very small bright line also seemed to appear near 1474 for an instant, but as it could not be seen again its existence is doubtful.

The estimated relative brightness of the lines was C, 8.5; $D_3$, 5.5; 1474, 10.0; F, 3.0.

On the register plate—

Set No. 1 are the observed lines.

Set No. 2 are standard dark lines, commencing with C on the left, taken after the eclipse in a very imperfect light, and are not very reliable; on this set are two erased lines.

WALTER PYE.

JEREZ, *December* 22, 1870.

In order to bring out one or two points more clearly, I addressed to Mr. Pye a note making a few inquiries, and received the following as an appendix to his report:

*Supplementary.*

1. For about two minutes before totality the eyes were shaded according to your directions.
2. I should imagine that the duration of the number of bright lines was not longer than was sufficient to produce an impression on the retina, or less than $\frac{1}{8}$ of a second.
3. I had in no way been prepared to expect this phenomenon, (*the reversal of the Fraunhofer lines.*)
4. No continuous spectrum was seen after totality until the slit was opened, when it could be easily seen; at neither time were any dark lines observed.
5. The slit was opened until the regulating screw did not act upon it, about $1\frac{1}{2}$ turns of the screw.* The *b* lines would certainly have appeared as a single line and probably indistinct.
6. The small bright line near 1474 was nearer than it to the red, that is to the left of the register plate. It should be mentioned that it was just at the close of the totality that it was looked for again, when it could not be found.

JEREZ, *December* 23, 1870.

*Subsequent careful measurement showed that the screw ceased to act upon the slit when its width was very approximately 0.2 of a millimeter.—Y.

MR. NORMAN'S TRACING OF THE CORONA.

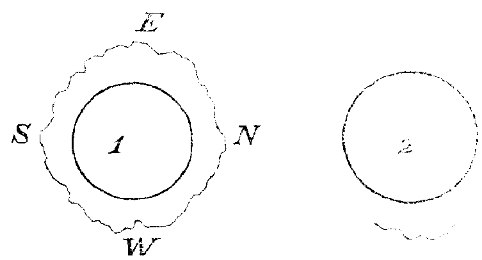
In accordance with an idea I had formed some time ago, I made arrangements to secure a tracing of the corona, hoping to ascertain whether there is any difference between the visible corona and the same thing as depicted by photography. For this purpose the comet-seeker previously mentioned, of 95 millimeters aperture, and 760 millimeters focal length, was employed. A diagonal eye-piece of low power was used, forming an image of the sun about 17 millimeters in diameter, upon a plate of glass very slightly roughened by grinding with the finest emery—just enough to give a hold to the point of a pencil. This image of the sun, seen by transmitted light of course, was very bright and sharp, and I was in hopes that that of the corona would be so likewise.

Mr. Norman, an English gentleman, resident in Jerez, and an artist of no inconsiderable skill, kindly undertook the instrument and during the totality made one tracing and commenced another, which are interesting when compared with the photographs.

He found, however, that the ground glass too much diminished the light, and he could not see on the plate many of the details (especially the dark rays) which were conspicuous to the naked eye. The drifting clouds greatly increased the difficulty.

If the experiment were to be repeated, I should propose that the tracing be made with a needle point upon a plate of gelatine or mica. I annex a copy of Mr. Norman's tracings.

(Mr. Norman's tracings.)




NATURE OF THE CORONAL LIGHT.

From the observations above reported, it is plain that the corona is to a certain extent self-luminous, and the self-luminous matter must of course be in the sun's immediate neighborhood. Its spectrum certainly contains *one* bright line, coinciding *exactly* with the dark line of the solar spectrum at 1474 of Kirchhoff's scale, this coincidence being just as well established as that of the red and blue lines of the protuberance spectrum with the hydrogen lines C and F. Whether the corona spectrum contains other bright lines is more doubtful, although the observations of Father Denza, quoted in a previous note, and my own observation in 1869, make it somewhat probable.

But while it is certain that the corona is in part self-luminous, it is hardly less so that it shines in part by reflected light, as indicated by the radial polarization, which seems to be pretty satisfactorily established by the polariscopic observations.

It might at first seem that if so the Fraunhofer lines must appear in the spectrum of this reflected light, but I think a little consideration will show that though they undoubtedly have a real existence, yet they must be so masked as to be very difficult of detection.

The total spectrum seen in an instrument like Mr. Abbay's or Mr. Pye's is, in all probability, composed of five or six different overlying spectra.

1. First we have the chromosphere spectrum, characterized by the hydrogen lines and $D_3$, derived from the prominences and those portions of the chromosphere not hidden by the moon.

2. In the second place we get a true gas-spectrum of the second order, in which 1474 is the most prominent if not the only line. The gaseous envelope from which this line is derived has been

called the *leucosphere*,* to distinguish it from the chromosphere, which it far exceeds in elevation and extent.

3. We have (hypothetically as yet, but very probably) a true continuous spectrum without any lines bright or dark, due to the incandescent solid or liquid particles near the sun—in other words, to meteoric dust or fog. For although it seems difficult to admit the theory of Mr. Proctor that the whole explanation of the corona is to be found in such meteoric matter, yet there is hardly room to doubt that it must contribute a very essential element.

4. We have as a fourth element the spectrum of the true sunlight reflected by the leucosphere and the meteoric dust. This light is characterized by its radial polarization, and could we examine it by itself I have no doubt we should easily find in its spectrum the Fraunhofer lines.

5. Overlying these is the light reflected by the particles of the earth's atmosphere, adding to the spectrum of course no new characteristics of its own, but only increasing the area and decreasing the intensity of the light and partially obliterating outlines and definition.

And if, as Oudemans supposes, cosmical dust between us and the moon is concerned in the coronal phenomena, then the light from this must also come into the account, a light much the same as that reflected from the particles of our own air, but with an added dash of true photospheric sunshine.

### EXTENT OF THE CORONA AS INDICATED BY THE SPECTROSCOPE.

It is, of course, matter of great interest to determine the extent of the true solar corona. But the problem is rendered difficult by the action of our own atmosphere, which, especially when the air is somewhat hazy, expands the limits of a nebulosity in all directions, and in such a manner that it is not easy to distinguish between the atmospheric extension and the true corona either by the eye, the telescope, or the spectroscope.

When the air is thoroughly clear, however, as in the eclipse of 1869, this atmospheric effect is probably insignificant, as was indicated by the fact that the hydrogen lines were sharply terminated at the boundary of the chromosphere.

This year, however, the case was quite different, and they were observable, as has been stated, as much as 4 or 5 minutes outside of their proper limits. It will not do, therefore, to lay too much stress upon the fact that Professor Winlock was able to follow the 1474 line more than 20′ from the sun's limb; and yet the difference was so striking between the behavior of the hydrogen lines, which exhibited a most marked discontinuity of brightness at the edge of the chromosphere, and that of 1474, which simply grew uniformly fainter with the increasing elevation, that, personally, I have no doubt that the boundary of the true corona had not been overpassed by Professor Winlock.

By combining, however, the observations of Mr. Pye with those of Professor Winlock and myself, it is easy to show that the luminous area, from which we derive the spectrum characterized by the 1474 line, is far more extensive than the prominences and that portion of the chromosphere visible during the eclipse.

I have ventured to call instruments like those employed by Mr. Abbay and Mr. Pye, *integrating* spectroscopes, since they sum up in the spectrum which they show the total amount of light of each definite refrangibility derived from the whole luminous area in the field of the collimator. This field is, of course, a cone defined by lines drawn from the edge of the collimator object-glass through the center of the slit, (neglecting the length of the slit,) and indefinitely produced. All the luminous particles within this cone contribute equally to the spectrum, and the instrument gives no means of determining in what portion of the field any particular line of the spectrum originates.

* This term "leucosphere," first proposed, I believe, by Lieutenant Brown, at a meeting of the Royal Astronomical Society, last January, is in some respects objectionable, but as it is convenient, and I am not aware that any better one is in use, I employ it provisionally. If, as is quite possible, it finally turns out that the non-solar elements of the corona are only insignificant, the word will become unnecessary; but while the question is under discussion it is desirable to have a name for that portion of the coronal luminosity which all concede to be solar.

Mr. Lockyer would extend the term "chromosphere" for this purpose, but that word is so satisfactory as a designation of the red hydrogen stratum that such an extension hardly seems advisable—especially as in that case we must invent some new name for the hydrogen atmosphere.

But on the other hand, when a spectroscope is attached to a telescope in the ordinary manner, the object-glass forms a definite image upon the slit when the instrument is accurately adjusted, and the spectrum seen is simply the spectrum of that elementary portion of the luminous body whose image falls between the jaws of the slit.

Used in this way, I call the instrument an *analyzing* spectroscope in antithesis to the other, since in this case we virtually separate the luminous area into its elementary portions and examine the spectrum of each portion by itself.

Now in the analyzing instruments, as nearly as I can estimate, the C line is from 25 to 100 times as bright as 1474, the light-ratio being about the same as that between a star of the first magnitude and one of the fifth or sixth. If we write 50 for the ratio I think we cannot be far from right.

In the *integrating* instruments, on the other hand, according to the observations of Professor Pickering, in 1869, and of Mr. Pye, above reported, (with which also agree the observations of Mr. Abbay so far as they go,) the 1474 line is the brightest visible. Mr. Pye gives for the brightness of 1474 the number 10, and on the same scale calls C 8.5; this would indicate between them a light-ratio of about $\frac{100}{72}$ in favor of 1474.

If then we suppose the corona and chromosphere each to be of uniform brightness throughout, we must conclude that the angular area (square minutes) subtended by the leucosphere is the greater in the ratio of at least $50 \times \frac{100}{72}$ to 1—that is, the solar corona is about 70 times as extensive as the portion of the chromosphere visible during the eclipse.

And if we were to take into account the fact that the chromosphere is more nearly uniform in its brightness and more definitely bounded than the leucosphere, it is evident that this ratio would be somewhat increased, since the comparison between the C and 1474 lines is made with the analyzing spectroscope very near the sun's limb, where the brightness of 1474 is far above its average—where only, indeed, it can be seen at all except during an eclipse. From comparisons of $D_3$ and F with 1474 we also get results substantially accordant with the above.

It is difficult to estimate accurately the aggregate area of the prominences and chromosphere visible during the eclipse; it was perhaps equal to a ring 9″ or 10″ high around the sun. If so, the leucosphere would appear to have an average elevation of about 10′, a result which agrees pretty well with the photographs and drawings, nor is it inconsistent at all with the idea that the long rays and fainter outside radiance may also be solar appendages.

But with reference to these rays, both bright and dark, the indications at present do not seem to be at all decisive. On the one hand the remarkable agreement between the photographs taken by our party in Spain, and those of Mr. Brothers, in Sicily, is an exceedingly strong argument for their solar origin. On the other hand, however, we have indications that point almost as strongly to a cislunar source. For instance, the curious appearances presented by Lord Lindsay's photographs, and the fact that in comparing different stations along the track of an eclipse we find that at some (as for instance Sioux City and Shelbyville, Kentucky, in 1869) these rays are conspicuous, while at others (Burlington and Springfield, in 1869) they are not seen at all.

Should it turn out that they are only visible at stations where the air is more or less hazy and turbid, they must naturally be considered as atmospheric phenomena, produced, of course, not by true photospheric sunlight, (which, as has been abundantly shown by many writers, cannot illuminate the air near the moon's place,) but by the light from the prominences and the lower regions of the leucosphere. If, on the contrary, as seems to be the case, this radiance appears under unexceptionable atmospheric conditions, we are almost shut up to one of two theories: either on the one hand that of Professor Norton and Mr. Proctor, whose views regarding these rays are nearly identical, and represent them to be streams of matter, similar to cometary substance or auroral beams,*

* Since my name has sometimes been referred to in connection with the so-called "auroral theory of the corona," it is perhaps proper for me to state that I make no claims to its origination. So far as I know, Professor Norton, of Yale College, was the first to publish a connected theory of the subject, basing his conclusions largely upon his discussions of Donati's comet, published some years ago in Silliman's Journal.

Professor Winlock also informs me that he has held and published a very similar opinion, and so, I believe, have driven by solar repulsions; or, on the other hand, that of Oudemans, who considers them to be purely optical effects produced in cosmical dust between us and the moon by the sunlight streaming across the uneven and ragged edge of our satellite. Evidently the subject requires careful and patient study for its elucidation.

NATURE OF THE CORONAL ENVELOPE AND ITS RELATION TO THE SUN.

Another interesting series of problems relates to the substance composing the leucosphere and the relation of this envelope to the sun—whether it is a true solar atmosphere or a mere cloud of transient particles—a flock of meteors, as Mr. Proctor supposes.

Waiving the difficulty of supposing such a multitudinous and continual supply of meteoric matter as the theory would require, it apparently fails in accounting for the peculiar form assumed by this envelope, which seems to be deepest over just those regions where the spots are most numerous, and to be governed even in the minutiæ of its outline by the arrangement and magnitude of the prominences.

I find, also, another great objection to it in the powerful winds and cyclones which prevail in the regions above the chromosphere at elevations as great as fifty, and even one hundred thousand miles. These winds, by which the tops of the solar flames are whirled and driven, present, so far as observations now go, every characteristic of true aerial currents in a continuous medium; and the whole appearance and behavior of the protuberances, except at the moment of eruption, is that of clouds floating in an air. It is impossible to conceive any more exact resemblance than that which exists between these objects and the lighter clouds of our own upper atmosphere.

But if we then consider the leucosphere as a true solar atmosphere, how can we reconcile its enormous extent with the smallness of the pressure at its base, which seems to be established by the experiments of Lockyer and Frankland, as well as Wüllner?

There seem to me to be two possible explanations of this: first, and perhaps on the whole most probable, this atmosphere may consist of some new kind of matter whose density is far below that of even hydrogen; or, on the other hand, it may be composed of matter whose specific *gravity* (*not density*) is diminished, annihilated, or even rendered negative by some solar repulsion, such as appears to be operative in the formation of a comet's tail.

It appears to be certain, from the observations of Angstrom and Kirchhoff, that the 1474 line which characterizes its spectrum coincides with a line in the *iron* spectrum within the limits of any present means of observation; and so close a coincidence can hardly be accidental. Yet in the spectrum of iron this line is only a faint and unimportant one, one of the last to make its appearance under the stimulus of the electric spark, and so little conspicuous that Mr. Huggins has failed to map it.

It is, to say the least, very difficult to understand how, if this line be really of the same origin as its fellows, it should remain the sole survivor of changes which have exterminated all its stronger associates; accordingly it becomes natural to suppose, as I suggested in 1869, that in the spectrum of iron this line may be due, not to the iron itself, but to some associated substance, (possibly related to the peculiar magnetic properties of this remarkable metal,) to some occluded gas which can also exist free in a state of inconceivable tenuity, as we have it in the leucosphere, and probably also in the streamers of the aurora and the tails of comets—a near relative, so far as gravity is concerned, to the luminiferous ether and to the Urstoff of German speculators.

With this view I believe Mr. Lockyer agrees, so far, at least, as to think the leucosphere composed of a new form of matter.

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several European astronomers. My own father, more than twenty years ago, was accustomed to teach essentially the same thing; so that when in 1869 I discovered (as I supposed) the coincidence of the bright line in the corona spectrum with a line in that of the aurora and declared my belief in the essential identity of the phenomena, I considered myself as simply subscribing to a view already current, and bringing a strong argument to its support.

I may add further that a careful observation of the auroral spectrum with the best means I have yet been able to command, and an examination of the observations of others, have convinced me that while thus far nothing appears which is inconsistent with the absolute coincidence of the two lines, still it cannot be considered to be established.

I think the probable error of the position of this aurora line, which is an exceedingly difficult object, and has yet been observed only with single-prism spectroscopes, must amount to five or six divisions of Kirchhoff's scale.

But on the other hand it is certain that alterations of temperature and pressure produce great changes in spectra; and although I think no case is at present known where, in the course of such changes, one of the least conspicuous lines is the most persistent and the last to disappear, it is perhaps not impossible that this may be the case with iron, and that in the upper solar atmosphere the complicated spectrum of the metal may reduce to this single line.

It is certainly a curious circumstance, perhaps favoring this idea, that the other iron lines which from time to time appear in the chromosphere spectrum, are nearly all of about the same order of intensity as 1474; the more conspicuous iron lines like E and G are never reversed, while in the case of other substances their strongest lines are the first to become bright.

If, then, we admit a sufficiently repulsive force, it seems still possible to suppose that the leucosphere may consist of *iron* in the state of vapor and fog; and the well-known wide diffusion of this substance in meteoric matter makes it comprehensible how its lines should occur in the spectrum of our own aurora and in any other places where they may be found. It would seem that we must look to the physical laboratory for light upon this subject.

### CONSTITUTION OF THE SOLAR ATMOSPHERE.

From what has been said it is perhaps evident that I am disposed to accept a very simple view of the constitution of the solar atmosphere.

Without discussing the nature of the body of the sun, I may perhaps venture to assent to the views of Zöllner, who considers that the phenomena of the protuberances almost demonstrate the existence of a "*Trennungs-Schicht*," or *crust*, either solid or liquid, through which from time to time burst out these masses of incandescent hydrogen.

Over this, as it seems to me, lies the atmosphere, composed of vapors and gases, *each arranging itself or tending to arrange itself (according to the views of Dalton,) as if it were the only one in existence.*

That is to say the *magnesium* atmosphere is approximately of such elevation, and of such density at each elevation, as it would be if the only atmosphere of the sun were so much magnesium vapor as now exists there; it being supposed, of course, that by some extraneous means the surface of the sun be kept under the same pressure and at the same temperature as at present.

According to this view there is near the surface of the sun a certain layer, probably less than five hundred miles in thickness, which contains all the gases in intimate mixture; this is the birthplace of the Fraunhofer lines, and I suppose I obtained a glimpse of it at the moment when totality began.

Ascending, we successively pass the limits above which the different gases do not rise, these limits being lowest for the vapors of greatest density; the hydrogen and the unknown $D_3$ element, on account of their lightness, reach a much higher level than the others, while far above even these towers the coronal matter.

Of course I do not intend to ignore the enormous vertical and horizontal movements which agitate this atmosphere, originating, mainly, it would seem, in forces acting from beneath, giving to the upper surface of the chromosphere a form as irregular and fantastic as a sheet of flame, elevating its general level to some extent, and often carrying up magnesium, sodium, and iron to the very summit of the prominences.*

Considering also the close and immediate connection between unusual disturbances on the solar surface, and magnetic storms on the earth, it is altogether probable that this wild commotion is accompanied by a development of electric force abundantly sufficient to account for all the observed resemblances between the corona and the electrical phenomena of our upper atmosphere.

* There is another view of the solar atmosphere which may perhaps be tenable. Since it is unsafe to take the non-detectibility of a substance by the spectroscope as a proof of its absence, it is perhaps not impossible to assume that the solar atmosphere is roughly homogeneous throughout; only in this case we must also assume the very doubtful fact that the denser gases lose their luminosity at higher temperatures, and consequently at lower levels. Accordingly when we find the sodium lines reversed in a prominence, it would indicate, not the bringing up of sodium from a lower level, but the raising of this portion of the solar atmosphere to a higher than usual temperature.

But I do not see how we can reconcile a homogeneous atmosphere of such elevation with the undisputed smallness of the pressure at the sun's surface, to say nothing of other difficulties hardly less serious.

I am aware that there are objections to the theory I have indicated, arising from the phenomena of the diffusibility of gases, but so far as I can see they are not conclusive against it. One thing is certain, that too much caution can hardly be used in applying conclusions derived from laboratory experiments to the solar atmosphere, where the circumstances are so widely different.

### SUGGESTIONS WITH REFERENCE TO THE OBSERVATION OF FUTURE ECLIPSES.

At the request of Professor Peirce I annex the following notes with reference to methods of observation, and points to which special attention should be directed in future eclipses.

#### A.—*Photography.*

1. Photographs of the partial phases by Professor Winlock's method, with a lens of long focus, for the purpose of determining the relative positions and motions of the centers of the sun and moon.

2. Photographs of the corona made with a telescope of large aperture ($30^{cm}$, if attainable,) fitted with a lens near the eye-end, like the Barlow lens, only *convex* instead of concave. This lens to be of such focus and so placed as to reduce the diameter of the solar image to about $7.5^{mm}$, or $1^{cm}$.

This lens can be made to improve the corrections of the object-glass for the actinic rays. Great care should be taken in adjusting the diameter of this lens, and the size and position of all stops and diaphragms, not to interfere with light coming from any point within $1\frac{1}{2}^{\circ}$ of the sun.

With an object-glass of the size mentioned we might expect, I think, to get a strong picture of the whole coronal region, with an exposure not exceeding 5 seconds, and a series of such pictures would infallibly settle the question as to how much of the phenomenon is cis-lunar.

3. As a substitute for the above, photographs taken with a camera of wide angular aperture carried by an equatorial mounting and clock-work; or simply strapped to the tube of an equatorial, which could be in use for viewing or sketching, without interfering with the photography.

4. Photographs of a prominence highly magnified, the image being thrown up by an eye-piece to a scale of from 5″ to 15″ per millimeter, so as to give the details. This would, of course, require a large telescope, with accurate driving-clock, and perhaps is hardly of sufficient importance to justify the expenditure.

#### B.—*Spectroscopic observations.*

1. Determination of the instants of first and last contact.

2. Careful examination of the cusps to see if the moon's limb in any way modifies the spectrum. Brushes of red light have been reported by some observers as appearing at the cusps; if so, what is their spectrum?

3. Close to the sun's limb look for a layer in which the Fraunhofer lines originate. Just before totality it should give a nearly continuous spectrum, and just at the moment of totality should show all the dark lines of the spectrum (excepting of course those of terrestrial origin) reversed. The spectroscope employed cannot have too high dispersive power. The image of the sun should be not less than 1 inch in diameter, and since the thickness of this layer does not exceed $\frac{1}{1000}$ of the sun's diameter, evidently the most critical care must be exercised in reference to all the adjustments for focus, &c., and the slit should be very narrow.

4. Determine the thickness of this layer by noting how long the lines continue bright. This will require a chronograph capable of being read to $\frac{1}{100}$ of a second.

NOTE.—It is possible, as has been stated before, that no such layer exists, and that the phenomenon seen by Mr. Pye and myself was due to some unusual disturbance of the sun's surface.

5. Examine the prominence spectrum carefully for new lines just before and after totality, when the atmospheric glare is greatly reduced. Examine specially the upper part of the spectrum above F.

If there are observers enough to attend to other points, continue the observation through totality, particularly noting whether any diffuse band appears over *b* (not higher up in the spectrum, but replacing *b* at greater distance from the sun,) and whether the F line runs higher than the other hydrogen lines.

The upper part of the prominence spectrum deserves, and will probably repay, careful study, and is very difficult to deal with except during an eclipse.

Use a spectroscope of high dispersive power.

6. With a similar spectroscope having the slit *slightly* widened, examine the spectrum of the corona for new lines, especially between 1474 and $D_3$.

The telescope employed should be of large angular aperture, giving an image of the sun about $1^{cm}$ in diameter.

7. With the same instruments interpose a Nicol's prism in front of the slit, and note the effect, if any, upon the spectrum of the corona when the Nicol is rotated; but any results thus obtained must be carefully considered and checked, being complicated by the polarization produced in the refraction through the prisms. Place the slit at several different points and different angles with the sun's limb.

8. With the same instruments (except the Nicol) but with *widely* opened slit, study the "dark rays;" if they are really channels in the monochromatic leucosphere their outline will be visible through the slit in the same manner as the forms of the prominences. It is hardly necessary to add that all the spectroscopes used in the above-mentioned observations ought to be *automatic*, and provided with some accurate registering apparatus.

9. Examine the appearance of the eclipsed sun with a "meteor-spectroscope"—having no collimator or slit. So far as the corona is monochromatic it will be *distinctly* seen notwithstanding the prism, while those portions of it which shine only by reflected sunlight will be indistinct, their light being dispersed. Even without a telescope the same object may be attained, to some extent, by merely looking at the corona through an ordinary prism or a direct vision combination.

10. Repeat the observations with the integrating spectroscope. There are some curious discrepancies between the observations of Mr. Abbay and Mr. Pye which need to be cleared up.

C.—*General telescopic observations.*

1. During the partial phase look for the projection of the moon beyond the sun's limb and for brushes of light at the cusps.

2. Notice whether the coronal radiance shifts from one side of the moon to the other during the totality, using considerable aperture but very low magnifying power.

3. In order to secure accuracy in sketching, insert in the focus of the object-glass a transparent plate divided into squares, or marked in some other systematic manner, and use a paper marked off to correspond.

4. Look for spots of light on the moon, and examine carefully the gradation of light from the limb toward the center during totality.

5. Look for intra-Mercurial planets.

6. With all the telescopic power available examine the structure of the corona to ascertain whether it is made up of filaments; and, if so, whether they are straight or curved; and, if curved, whether they are *concave* or *convex* toward the sun.

7. Observe carefully whether there are any *nuclei* in the corona—anything like "resolvability" of a star-cluster.

D.—*Naked eye or field-glass observations.*

1. Changes in the corona, such as shifting of the light from one side to the other of the moon, alterations in the position of the dark and bright rays, &c.

2. Observe whether the external radiance, into which the rays appear to reach out from the leucosphere, presents any distinguishable outline; and, if it does, of what character.

3. Look for narrow dark and light bands moving over the surface of the earth just at the moment of total obscuration.

4. Notice what portion of the sky is darkest, and how the light varies from this to the brighter portions.

E.—*Physical observations.*

1. With a thermopile and galvanometer measure the total radiant heat from the corona, and test it for "quality" by interposing various transparent screens of known thickness. Compare it with the heat received from the uneclipsed sun by means of a vessel of boiling water or some other constant source of heat.

2. Forming the image of the corona in the focus of a telescope, test the different portions of the image with a minute thermopile of a single pair, in order to ascertain the relative intensity of the heat from its different parts. Especially ascertain how much more heat comes from the prominences than from neighboring portions of the corona.

With respect to polariscopic and photometric observations I have nothing to offer.

With the greatest respect, I am, dear sir, yours very sincerely,

C. A. YOUNG.

Professor J. WINLOCK.

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POINTS TO BE SPECIALLY ATTENDED TO IN THE OBSERVATION OF FUTURE ECLIPSES.

A.—*Photography.*

1. Photographs of the sun during the partial phases of the eclipse, with a lens of from 8 to 16 meters focal length, according to Professor Winlock's plan, for the purpose of determining the relative position of the centers of sun and moon.

2. Photographs of the corona made with an equatorial of large aperture (25 to $30^{cm}$ if possible) fitted with a lens near the eye-end like the Barlow lens so-called, except in being convex instead of concave. This lens should be of such focal length and so placed as to reduce the diameter of the solar image to less than $1^{cm}$, and could be made to improve the corrections of the object-glass for the actinic rays. Special care must be taken to avoid interference with the impression of anything within three or four degrees of the sun by any stops or diaphragms. The object, of course, should be to secure such a series of pictures as will show whether any changes take place in the coronal streamers; and, if so, whether they stand in evident relation to the moon's motion and the inequalities of her limb.

3. Photographs with an ordinary camera strapped upon the tube of an equatorial driven by clock-work, or else arranged with its optic axis parallel to the axis of the earth, and having the light thrown in by the flat silvered mirror of a Meyerstein heliostat, I think not so good as the preceding.

4. Photographs of the most remarkable prominences, on a large scale for the purpose of studying their details. The image of the sun should be thrown up by an eye-piece to a diameter of from 15 to $20^{cm}$, *i. e.* the scale of the photograph should be about $10''$ to the millimeter. This would of course require a large telescope.

B.—*Spectroscopic observations.*

1. Observations of the instant of first and last contact by means of the occultation and re-appearance of the chromosphere.

2. Careful examination of the cusps during the partial phase to ascertain if the moon's limb appears to modify in any way the spectrum of the chromosphere. Brushes of red light have been reported by some observers as appearing at the cusps; if so, what is their spectrum.

3. Look for a stratum close to the limb of the sun giving a nearly continuous spectrum just before the eclipse becomes total; and at the moment of totality giving a spectrum in which the dark Fraunhofer lines are all reversed.

Pretty high dispersive power, and a very accurate adjustment of the slit in the exact focus of the collimator, are essential; also care in placing the slit exactly tangential to the solar image, and precisely in its plane.

The observation is important because, though unlikely, it is certainly not impossible that some unusual chromospheric storm, such as Mr. Lockyer has once seen, may have produced the phenomenon observed by Mr. Pye and myself.

4. If the stratum is found, determine the precise duration of the reversal of the lines at the commencement of the totality by means of a chronograph, and repeat the observation at the re-appearance of the sun, in order to ascertain the thickness of the layer.

5. During the partial phase, especially near the time of totality, examine with the highest dispersive power available the more refrangible portion of the spectrum for new prominence lines. If an observer can be spared, this ought to be done also during the totality. This upper portion of the spectrum needs to be much more thoroughly studied than has yet been done.

6. With a spectroscope of high dispersive power attached to a telescope of large angular aperture, giving an image of the sun not more than $1^{cm}$ in diameter, examine the spectrum of the corona for new lines, especially determine whether there are any between $D_3$ and 1474. For this purpose the slit may be slightly widened. Also note the extension if any of the hydrogen lines above the chromosphere and upon the moon's disk.

7. With the same instrument and widely opened slit search for monochromatic radial beams; if any such exist they can be seen through the 1474 line in the same manner as the prominences are studied through C and F. In this way the structure of the corona will also probably come out more distinctly, being cleared of the diffuse light from other sources.

8. Place a Nicol's prism in front of the slit of the instrument, and note the effect, if any, of its rotation upon the spectrum of the corona. But on account of the partial polarization of the light in its refraction through the prisms, any results thus obtained must be received with reserve, and carefully checked.

9. Examine the appearance of the sun through a so-called meteor-spectroscope, (having no slit or collimator.) So much of the corona as gives the monochromatic light will be *distinctly* seen, while the rest will be made indistinct. The same object may be obtained by looking at the sun with the eye naked, and armed with a small telescope, through a prism, or, better, a train of 5 or 6 prisms.

10. Repeat the observations of Professor Pickering in 1869, and of Messrs. Abbay and Pye in 1870, with an integrating spectroscope, *i. e.*, a simple chemical spectroscope unattached to a telescope. There remain discrepancies which need to be cleared up. It is *exceedingly* important that in all cases when possible the observer of the spectroscopic phenomena of totality should have had his eyes carefully prepared by previous seclusion in darkness for some 4 or 5 minutes.

### C.—*Polarization.*

I leave this subject wholly to Professor Pickering and others.

### D.—*Photometry.*

I have nothing to offer.

### E.—*General telescopic observations.*

1. Look for the projection of the moon beyond the disk of the sun, and for brushes of light at the cusps.

2. With considerable aperture and very low power notice whether the coronal radiance shifts from one side of the sun to the other during the totality.

3. For the purpose of securing accuracy and rapidity in sketching, use paper previously divided into compartments on some convenient plan, and in the focus of the telescope (using, of course, a positive eye-piece) insert a piece of plane glass or mica marked in the same manner.

4. With considerable power study the base of the corona to ascertain, if possible, whether the curvature of the filaments is *convex* to the sun, indicating a *repulsive* force.

5. With all the telescopic power at command look for *nuclei* in the corona, or for any signs of meteors or comets in the sun's immediate neighborhood.

6. Possibly it is worth while to continue the search for intra-Mercurial planets.

7. Observe differences of color between the different parts of the moon's disk, or bright spots upon it.

F.—*Naked-eye observations.*

1. Note any changes that occur in the appearance of the corona during the totality, and differences of color in its different parts.

2. See if the outer boundary of the corona is like the boundary of a *cloud*.

3. Look for the dark bands reported to move over the surface of the earth at the moment of totality by Secchi and others.

4. Note what portion of the sky is darkest during the totality—it should be a *ring*.

G.—*Physical observations.*

1. Measure the radiant heat from the corona with a thermopile and galvanometer without a telescope and ascertain the effect of interposing different transparent screens of known thickness, (*e. g.*, a screen of glass, a screen of quartz, a screen of alum, &c.,) in order to ascertain the *quality* of the heat.

2. With a linear thermopile (like that used in Rosse's experiments upon the moon) explore the image of the corona formed in the focus of a telescope in order to ascertain the relative temperatures of its different portions.

3. Having suspended a small magnet by a wire in such a manner that it shall be maintained at an angle of about 30° with the magnetic meridian, observe (by means of a mirror attached to the magnet, and a telescope with a scale) whether the magnet *twitches* at all as the moon in its progress covers or uncovers spots and prominences, and especially whether it experiences any unusual disturbance at the beginning or end of totality. (I do not expect any.)

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ALLEGHENY OBSERVATORY,
*Allegheny, Pennsylvania, April* 15, 1871.

SIR: I have the honor to submit the following report of the observations made by me, with the party under your charge, at Jerez, Spain, on the solar eclipse of December 22, 1870.

Together with Captain Ernst, Professors Young and Pickering, Mr. Ross, and some members of the Sicilian party I left Southampton, England, on the 26th of November, in the Peninsular and Oriental Company's steamer Poonah, and reached Gibraltar on the evening of December 1. Here we staid some days awaiting a boat for Cadiz, and as it seemed uncertain when the regular steamer would leave, Captain Ernst and I started in advance of the rest of the party in a small Spanish vessel, reaching Cadiz on the 8th and Jerez on the 9th of December.

I had limited the instruments taken with me, by your advice, to a small portable telescope, a Savart's polariscope, and to a polarizing solar eye-piece, and to these was added at Jerez an equatorial telescope of 4 inches aperture, without clock-work or circles, the property of the Harvard College observatory. This instrument had been fitted with a small spectroscope, which was removed some days before the eclipse. The instruments actually employed by me were the following:

1. The equatorial just mentioned. It has a good objective, which I have frequently used on close double stars with high powers, the images being sharp and free from diffuse light. Tried by all usual tests it is a more than ordinarily good glass, and if no positive results were obtained by the direct study of the coronal structure with it, it was due to no defect of the instrument. The mounting is by Troughton & Simms, but the tube was for the occasion bolted to an equatorial stand of iron, made by Messrs. A. Clarke & Co. for another telescope. This iron stand rested on a pier which I had made of the only accessible material: two pieces of joist sunk to the depth of three feet below the soil, surrounded by well-rammed earth, and united at the bottom and at the

top by a capping of 2-inch plank. The iron stand was intended for use in a more northern latitude, and to bring it to approximate adjustment, the top of the wooden pier was cut at such an inclination that the bed-plate, when bolted down, was inclined at a sufficient angle to its normal position to bring the polar axis to the needed inclination. The other adjustments of the instrument were made with as much accuracy as the absence of its circles permitted, and as its chief office was to enable the observer to follow the sun during the brief time of the eclipse, this was more than sufficient. Still attached to the tube was the finder, a small telescope of about 1½ inches aperture.

The iron bed-plate and the hollow cone for receiving the polar axis, which were cast in one piece, were bolted to the pier, but the tube with the polar axis attached was not too heavy to be lifted by two persons, and transported at night or during rain to the shelter of the adjacent building.

2. To the finder of the large telescope was applied the Savart's polariscope, with which it was intended to study the corona, with special reference to the plane of polarization; a matter as to which previous observers were not agreed. As the Savart is an instrument which, though well adapted to detect minute proportions of polarized light, presents its results in a form easily misconstrued, it will be well to describe the one employed, and the precautions taken to insure its proper use. This is the more necessary as many of the observations made by its aid in previous eclipses are so given in published accounts as to leave their real meaning in doubt, and on this occasion the results appeared to be conclusive as to a point hitherto open to question.

3. The principal telescope above described was intended for the study of the intimate structure of the corona, near to the sun, but as the power which it seemed best to employ was much too high to enable the observer to view the whole disk at once, a second telescope was used to save the loss of time in exchanging eye-pieces. This was a smaller instrument, moving in altitude and azimuth, on a tripod stand. It was of about 3 inches aperture, and 3½ feet focal length, and was used with a terrestrial eye-piece of a power of 30 diameters, which embraced the whole of the sun, and of the actually seen corona, in one field of view. A heavy wire in the eye-piece could be rotated, and set at any estimated position angle.

I had been deeply interested by the appearance of the outer coronal rays, extending to perhaps a solar diameter from the moon, which I saw in the eclipse of 1869, with insufficient optical aid. More lately it seemed, from the unpublished testimony of at least one trustworthy observer, that the coronal structure near the sun was even more remarkable. More, in fact, than one had already seen or believed himself to have seen it, filled with curves approximately hyperbolic, with their vertices turned toward the sun; and drawings made by observers at earlier eclipses, when rescrutinized, were found to lend countenance to the idea that such a structure had before been seen, though it might have been imperfectly noted.

The interesting inferences to be drawn from such a fact would be evidently premature, till so singular and unanticipated an observation had received general confirmation. At the same time, the study of the structure of the external rays, so remarkably striated, (as they appeared the year before,) promised to throw light on the question of their solar or terrestrial origin.

I felt, therefore, that the use of the spectroscope and polariscope would not supersede the necessity of direct telescopic scrutiny; and hoping, with a good instrument and attention chiefly directed to this point, to obtain evidence on disputed questions of interest, I gladly found this class of observation, together with the use of the polariscope, assigned to me.

Knowing that Professor Pickering was to devote himself exclusively to polariscope phenomena, I arranged my own work so that our observations might as far as possible be supplementary to each other, and, having decided to give only a limited part of the two minutes of totality to this, judged that it would be best to attempt only what there was time to do deliberately, and to confine myself to a determination of the existence or non-existence of radial polarization.

Owing to the weather, the direct observations, as it will be seen, though not without interest, were indecisive of the points previously mentioned, and the results obtained with the polariscope assumed relatively more importance. I return, therefore, to a description of the preparations made for the use of the latter instrument.

The Savart's polariscope, which I used, is of the usual size, having a Nicol's prism of about 3-inch aperture, and crossed plates of quartz, which had been adjusted imperfectly by the maker.

To use the instrument to the best advantage, the quartz plates were together rotated, relatively to the Nicol, till the bands attained their greatest intensity, and in this position they were then permanently fixed, so that thereafter prism and quartz plates had but one motion of rotation together. In this position the central band is in the principal section of the prism, and the quartz and Nicol being relatively fixed, and the instrument receiving light polarized in one plane, the colors attain their maximum intensity, when the bands are parallel to the plane of polarization; (in this case the central band is dark;) and again they are at right angles to it, (in this case the central band is white.) Of the colored bands in the particular instrument employed, ten or twelve are distinctly seen, each being over one degree in width, so that when the little instrument is directed to the moon, its disk is more than covered by one of them, and the corona cannot well cover two of the bands at once.

It is desirable, however, that several of the bands should be seen projected on the source of light, and accordingly the polariscope was adjusted to the finder of the telescope already referred to, and the magnifying power (linear) being about twelve times, the image of the moon was now found to cover four of the bands with their intervening spaces. No sensible polarization was caused by the glasses of the finder. Let the telescope be now directed to the reflection of the sun in water at apparent noon, and let the polariscope be rotated till the bands attain their maximum intensity, at which time, if parallel to the plane of polarization, they are vertical and with the black band central, presenting the appearance indicated in the accompanying sketch (Fig. 1, Plate No. 28,) except as to color.

The circle gives the relative size of the moon's disk. For distinction, this may be called the normal position of the instrument, whose relation to the telescope is also given, when that is stated to be east or west of its pier. The upper part of the milled edge at the eye-end is now marked by filing a notch deep enough to be distinguished in the dark, and the adjustment is completed under conditions which can be reproduced at any time, and are not likely to be mistaken.

If the Savart, still directed to the water, be rotated, the bands rotate with it, growing fainter till it has been turned through 45°, when they vanish; appearing again as the rotation continues, and growing stronger up to 90°, when they are horizontal and again at a maximum of intensity, but with the light band central. At 135° they have again disappeared, and at 180° have resumed their original appearance. The same changes, in the same order, are repeated through each half revolution.

If we suppose the instrument to be left undisturbed in its normal position, but the plane of polarization of the incident light to be rotated, the same phenomena will present themselves as before.

The bands remaining vertical, they will disappear when this plane has been rotated through 45°, re-appear in full intensity with the light band central at 90°, and so on.

If we now suppose a point of light behind the center of the image of the moon in Fig. 1, and that the light is polarized in radial planes passing through this point and the eye of the observer, it is not difficult to anticipate and render an account of the appearance to be presented. It is conventionally shown in Fig. 2, Plate No. 28. The directions of four out of the infinite number of planes of polarization are represented by dotted lines.

The central band is in the vertical plane passing through A B. It will present a uniform intensity thoughout. The extremities of the next band, C D, are crossed by the radial planes at a slight inclination near C D and at a greater and greater, as the diagonal H I is approached. Near C the intensity of the band will be slightly diminished, and it will grow progressively fainter, till it crosses the ray polarized in the plane of H I, where the band (since it here makes an angle of 45° with the plane of polarization) will disappear altogether, regaining its intensity as it approaches the horizontal line, and repeating the same changes in an inverse order to D. Similar effects will be presented, with easily recognized modifications in the other bands, so that the general appearance will be as in Fig. 2, Plate No. 28.

We have now considered the effect which may be anticipated in viewing light, radially polarized, and it is the appearance which the corona would be expected from the theory of our instrument to present, if its light were polarized only in planes passing through the *center* of the sun.

Since the sun, however, emits light from every point on its surface, and is a sphere of dimensions very considerable in relation to the size of the corona, the appearance to be presented at an eclipse can hardly, on any theory, be expected to be that of strictly radial polarization. On subsequent reflection, while preparing this report, it has seemed to me that the modifications due to this relatively great size are more important than would at first appear, and may explain the fact that the bands at the time of the actual eclipse were not traced up to the limb. At any rate, the word "radial," which is frequently used as if the sun's dimension could be neglected in discussing the phenomena of polarization in the corona, must not mislead us as to the fact that it is incorrect, if used in any other than the general sense in which, for want of a better, I employ it.

It seemed proper, before the eclipse, to rehearse the observations then to be made; under circumstances so varied as to give similar conditions to any which it could be anticipated might present themselves.

Professor Pickering and I prepared a very simple apparatus, which enabled us to do this. Behind an opaque disk, subtending an angle of half a degree, was placed a lamp whose light was reflected to the eye by a suitable device, so as to be polarized in any single plane desired, or else radially in all planes passing through the hidden flame and the eye, at the pleasure of the experimenter. From trials with this artificial corona, it seemed that the Savart, though very readily indicating the existence of small proportions of polarized light, did not so readily distinguish between planes of polarization at right angles to each other, as not to make me anticipate difficulty in determining whether the plane of polarization of the real corona was vertical or horizontal (supposing it to be one or the other.) This difficulty will be understood when it is remembered that while the plane moves from 0° to 45°, the appearance is radically altered, but the effect produced is the same at 0° and at 90°, save for a difference in the central band, only recognizable on careful scrutiny.

Again, when the light was radially polarized, though the appearance indicated in Fig. 2 was not well marked with feeble light, a reliable criterion of *this* condition was found even then to exist, by rotating the instrument. If the light was polarized in a plane, either vertical or horizontal, the bands disappeared at an angle of 45°, but they continued equally visible at all angles of position if the polarization was radial.

I should not mention the preparatory work with Professor Pickering without expressing my indebtedness to him for the kindness with which the results of his extensive and exact knowledge of the subject were placed at my service. Of his special familiarity with everything, pertaining to polarizing instruments in particular, I availed myself with an advantage that I take pleasure in acknowledging.

The morning of the 22d was cloudy, and gave at one time little prospect of our seeing the eclipse at all, and after the equatorial telescope was placed on its pier the rain fell so that it was necessary to cover it.

When all was ready, in the condition in which it had been arranged the day before, the equatorial was on the east of its pier, and the Savart polariscope adjusted to the finder, in the normal position described.

The small telescope was on a stand so near that any of the three instruments could be looked through without the observer's rising from his seat. Very light neutral-tint shades were used on the eye-pieces of both telescopes. The position of these instruments was the most southerly of any at the station.

As the time of first contact approached the sun was covered with a very light haze, over which thin clouds were drifting. I had intended to watch for first contact, but having no charge connected with observations of precision, on finding that Professor Young wished to watch the approach of the moon on the chromosphere, I offered to count time for him. I did so, and heard him say, "There it is!" some 12 or 15 seconds before the actual contact, which was unfortunately hidden from the spectroscope by a cloud. Returning to my own station, I awaited the approach of totality there, and was noting the irregularities of the lunar disk, about the point where second contact would take place, when clouds covered the sun altogether. No trace of polarization was up to this time visible about the solar disk. Shortly after, rain began to fall, and the instruments were left covered, while I retired to the shelter of the tent.

I presume that all present must recall the depressing influence of the cloudy sky, which nearly hid the sun till the approach of totality. Not 15 minutes before the critical time which was so anxiously awaited, it seemed to me that the good fortune which saved us was almost beyond hope. The sky was at that time nearly uniformly dark, and even when I took my seat again, a few minutes before totality, it seemed as if there was little chance. As the moment approached, the clouds broke in the vicinity of the sun, whose thin crescent now showed through the diminishing haze. The darkness was not great; and deceived as to the remaining time by this, and by the irradiation which enlarged the crescent, I bent forward to look at my watch. Just as I turned my eyes, I heard some one call, "There's the corona!" and looking up, saw it surrounding the sun like a low-burning flame. I had intended to notice how long it was seen before totality, but I cannot give this time with precision. *After* seeing the corona, the so-called "Baily's Beads" were formed, and disappeared, the crescent breaking where the prominence on the lunar limb had before been noted, and this must have occupied at least two seconds. I turned to the larger telescope, which was directed to the eastern limb of the sun, now just covered by the moon. Under the magnifying power of 140 diameters, there appeared a uniformly diffused nebulosity.

No suspicion of structure existed, except for one feebly marked "dark ray," which was straight-edged, as a shadow projected on the misty light, and almost exactly radial. Except for this, the coronal light was uniform in the narrow field.

The base of the ray in question had a position angle of about 70° reckoned from the true vertex toward the left.

After some 30 seconds of intent but fruitless scrutiny, I turned to the polariscope. The haze at this time was very slight indeed, and at one moment the sky to the naked eye was distinctly blue.

On looking into the Savart, the field which a few minutes before was vacant of bands was now traversed by them, vertically disposed of course, (since it was still in its normal position,) but surprisingly distinct for the light, even their color being visible. They ended before reaching the edges of the field, which embraced about two degrees, and did not appear to be traceable up to the disk. I now commenced turning the little instrument; moving the notch which marked the vertex toward the right. I had tried to bring to this observation a mind free from the bias of any preconceived opinion, yet, as I am since conscious, I turned it under a certain prepossession that the polarization would prove to be in a plane either vertical or horizontal, in either of which cases the bands would vanish at an angle of 45°. When this point was reached, they were as vivid as before. I paused to assure myself of the fact, (looking at and feeling the mark on the circle,) and then slowly continued the rotation till it had been carried through 180°. In all angles the band normal to the limb was the best marked, but all the bands remained distinct enough to show color in any position. Their extent from the sun I cannot give, yet as they were not distinguished with certainty at the edges of a field 2° in diameter, I should rudely estimate this average extent at 40′. I could not, as I say, follow them up to the moon's limb, and their increasing faintness as they approached it was noticed. I did not see any bands on the moon, but my attention was directed so exclusively to verifying their persistence around it, that little weight should attach to this negative evidence. When the polariscope had been turned through a half revolution, it had rendered all the evidence to be obtained from it, but for greater security the rotation was continued through nearly 180° more. There was no other result. There were no maxima or minima of intensity corresponding to one position angle more than another.

I now turned to the smaller telescope, and placed the bar prepared in the eye-piece for that purpose, in the direction of the longest diagonal of the corona, which was roughly quadrangular in figure. I again looked at it for a few seconds with the naked eye, and without difficulty read a sentence from a printed paper lying on the table by the diffused light of the sky. The general light about me seemed much more than that of the clear sky of the eclipse of 1869.

Next, setting the larger telescope on the western side of the moon, behind which the sun was to appear, I resumed the scrutiny of the corona near the limb, without any new result till the two minutes and ten seconds of totality had ended. Other observations of less importance had been made with the naked eye while darkness lasted; the principal results of all were written down before rising from my seat, and when I joined the other members of the party, it was with that painful feeling that precious opportunity has gone by without having been made the most of, which seems to be commonly experienced at such a time, though all may have been done one can do.

As we exchanged experiences, however, it appeared that each had something to add. How interesting the results of other observers were will be elsewhere told; on hearing them, all must have felt that we had as a party more reason to congratulate ourselves on the success achieved than to regret that it was not more absolute.

Such observations as I obtained are gathered in what follows.

### NAKED-EYE OBSERVATIONS.

These, it should be said, were made incidentally to other work on which the attention was chiefly fixed. They were necessarily therefore hurried, and are doubtless a very partial presentation of the phenomena that might have been gathered if they had been the principal object.

The first appearance of the corona was at least two seconds before totality. Its outline was very irregular, the edge not so much serrated as looking like tongues of pale flame. I may compare it to the low flame of burning grass in a distant prairie fire, but the comparison is not exact as to color or motion. No color was noticed but a pearly white, and there was no certain scintillation or movement. The height of this portion of the corona was not, I think, over 5′, and it might have been much less. It was viewed in this condition only for a few seconds, and its light was so vivid that irradiation in all probability exaggerated its apparent size. A sketch taken by Mr. Gordon, of Jerez, excellently renders its form, though its dimensions there are somewhat greater than I should estimate them.

During all the time of totality, the moon's disk was lighter near the circumference than at the center. The light could be followed for perhaps one-third the radius inward. No flush of light was seen to pass over the whole disk, either at the commencement or close of totality, though this was watched for. The chromosphere was not distinguishable, except that one or two of the prominences could be seen, though they were inconspicuous. On looking at the outer edge of the corona, a second time, when the middle of totality was reached, its appearance seemed changed, probably on account of the mist, and the edge was more diffuse. Still, the average width of the readily-seen corona was at no time to my perception much over 5′, in this respect contrasting very markedly with the impression made by that of 1869. I say "of the readily-seen corona," because beyond this it might be followed perhaps, but not with confidence. I suppose the phenomena here are to some extent "sub ective," and within what limits I have tried hereafter to estimate.

### DIRECT TELESCOPIC OBSERVATIONS.

The evidence from direct telescopic scrutiny is, owing to the lack of a clear sky, of chiefly negative character. The structure which has been alluded to, as seen or suspected by former observers, must be very inconspicuous, since, on the minutest examination, with adequate power, no trace of it could be found in a sky clear enough to show the phenomena already detailed. It will probably be unadvisable to give the time needful to verify or disprove its existence in any future eclipse which does not occur with wholly favorable atmospheric conditions.

The "dark ray" referred to, though very faint, was well defined and perfectly straight; it extended to the limits of the visible corona, and its width may be given, though vaguely, as probably within a minute of arc. It is probable, therefore, that it was not visible to the naked eye. The "red flames" were, of course, conspicuous, and beautiful objects in the telescope, though not more obvious or definite than when I viewed them through the C line of Professor Young's spectroscope the day before. The telescope during a total eclipse can add little to what the spectroscope now tells at any time of them, except as to their color, which the latter can only present by its components. The color, as directly seen, is to me that of the part of the spectrum midway between C and D, though some of the prominences are lighter than others, and nearer to an orange than to the "rose red," or "crimson," described by the observers of 1869. This will, perhaps, indicate that the gas or vapor giving the bright chromosphere line $D_3$ all around the sun, is yet in greater relative proportions in some parts of the chromosphere than in others, or under different pressure.

The direction of the greatest extension of the corona, as seen in the small telescope, was towards the northwest, and as approximately measured by the estimated position of the field-bar, it formed an angle of very nearly 45° with the vertical.

RESULTS OF POLARISCOPIC OBSERVATION.

I do not undertake to determine whether the presence of mist about the sun should affect the inferences now drawn. If we do not consider this objection, the following conclusions naturally result from the observations already detailed.

The light of the corona is, in the ordinary use of the word, radially polarized, though not in strictly radial planes if we have regard to the large relative size of the sun.

The outer limit to which the evidence of radial polarization extends is indefinite, but is probably not less than 35′ to 40′ from its circumference. The light close to the disk is not sensibly polarized. (This is, nevertheless, it seems to me, quite consistent with the possibility of this part of the corona's sending us much reflected light.)

Considering the evidence of very marked polarization elsewhere, we may infer, I think, that the corona is visible largely, if not chiefly, through reflected sunlight, a conclusion nowise contradicted, it seems, by the evidence of self-luminosity from the spectroscope. What precedes embodies all of consequence that my notes or memory supply.

On comparing the statements of different observers a fact of interest seems to have lately given rise to question. I refer to what has been called the "subjectivity" or "personality" of the individual, which has been supposed to affect his view of phenomena seen under circumstances of such mental tension as the brevity and importance of these observations often induce. As increased attention is being paid to this question, I may be permitted to recur to what I have noticed in myself, as affording some possible aid to its elucidation.

In August, 1869, the remarkable exterior rays or streamers forced themselves on my attention, (which was directed to an observation of precision,) almost to the exclusion of everything but the work in hand. I have no distinct recollection of then noticing, what was most apparent to others, the intenser inner light, for which a distinct title (leucosphere) has since been proposed. This year, again, other work left no leisure for deliberate naked-eye observations, and what I at this time casually noticed was the complement of that seen last year. Only the light at the disk was distinctly observed by me, (and by some others,) but at the same time, one competent witness, who was close by, but, like myself, chiefly engaged in other work, described the corona as having to him the appearance of *greater* extension than that of 1869. In my own case anticipation did not color what was seen, since in neither instance did I see what was expected. Probably these observations would have been accordant, but that in each case what was seen was seen furtively, and a part of the phenomena was impressed on the memory to the exclusion of others.

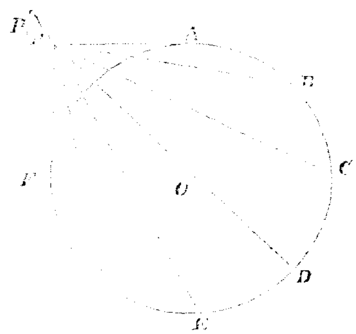
If this be, as it seems, a common experience under like conditions, to reconcile such observations with each other and the truth, it will only be necessary to apply the rule which ordinary experience teaches with regard to conflicting testimony. To do this, after eliminating as far as possible what is personal in the usual sense, such as individual deficiencies of perception as to color and so forth, we may, in discussing discrepant and presumably subjective phenomena, attach very little weight to negative testimony, but assume that what is most positive in the evidence of a conscientious observer is probably partial and incomplete rather than erroneous. If only the positive part of such testimony be collated, the rest of the so-called subjective phenomena must often cease to appear discrepant, and when superposed be complementary to, rather than contradictory of, each other.

I am, sir, very respectfully, your obedient servant,.

S. P. LANGLEY.

## NOTE.

Let the circle A C E F represent the disk of the sun; let P be a point in the corona at the intersection of two lines, P F, P A, tangent to the circumference at points F, A, 90° from each other, and let P be illuminated only by light from O, at the center of the disk. This light will be polarized by reflection in the plane whose trace is P D, and which (like the planes whose traces are P A, P B, P F, and so forth) passes through the eye of the observer. If an infinite number of points, illuminated only from O, as in this hypothesis, formed the corona, the appearance would be that due to strictly radial polarization.




But if P be illuminated from all points of the solar sphere which can send it light, that light will be polarized in the tangent planes P A, P F, and an infinite number between. More light may be received polarized in the plane of P D than in that of P C, and more in P C than in P B, yet it seems evident that reflected light, due to vibrations in an infinite number of planes at all azimuths, must be sensibly depolarized, at least so far as to make it much more difficult to determine the plane of maximum polarization at P than if there were but one, and that one radial. If P were at a distance, P O, in comparison with which the sun's dimension could be neglected, the polarization would again be wholly in the plane of P D. For all points, then, exterior to P the evidence of radial polarization will grow more marked; for all points nearer to O, less so.

Since similar considerations apply to every point in the corona, if its polarization be in a general sense radial, or such as would be due to directly reflected sunlight, we cannot, under the most favorable circumstances, expect evidence of it in the polariscope, from the parts very near the moon, during a total eclipse. Experience as well as theory shows that no such evidence can be found, and no conclusion against the presumption that the inner corona shines by reflected light should be drawn from its absence.

Such conclusions have been drawn, as it seems to me, erroneously, and it is therefore not superfluous to call attention to their apparent fallacy.

It is well also to remark, that if the above considerations are of any value, we are led to attach more importance to the independent evidence of the polariscope as to the extent of the corona, since evidence of polarization such as exists can only be drawn (as it here appears) from a region *outside* that to which some have believed the corona to extend.

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## REPORT OF OBSERVATIONS OF THE TOTAL ECLIPSE OF THE SUN OF DECEMBER 22, 1870, BY PROFESSOR EDWARD C. PICKERING, ASSISTED BY MR. WALDO O. ROSS.

BOSTON, *June* 19, 1871.

DEAR SIR: In preparing the following report on the polarization of the light of the eclipse of December 22, 1870, I have first compared some of the previous observations, then given the results of the measurement of the delicacy of different instruments, next shown what kind of polarization we should expect from theoretical considerations, then described the instruments used and the observations made with them, and finally given the conclusions to be derived and recommendations for future observations.

### PREVIOUS OBSERVATIONS.

The following table shows some of the principal polariscopic observations previously made, which I have discussed more at length elsewhere, (Journal Franklin Institute, January, 1871.) The first column gives the name of the observer; the second the point of observation; the third the date; the fourth the kind of polariscope used, and the fifth the conclusion as to the intensity or existence of polarization.

| Observer. | Location. | Date. | Instrument. | Polarization. |
|---|---|---|---|---|
| Arago | Perpignan | 1842 | Arago | Doubtful. |
| Mauvais | Perpignan | 1842 | Savart | Probable. |
| Abbadie | Fredericksworck | 1851 | Nicol & quartz | Strong. |
| Carrington | Lilla Ider | 1851 | Nicol | None. |
| Liais | Paranagna | 1858 | Savart | Feeble. |
| Secchi | Mount Michel | 1860 | Arago | Marked. |
| Prazmowski | Briviesca | 1860 | Biquartz | Very strong. |
| Campbell | Jamcandi | 1868 | Arago, Savart | Strong. |
| Winter | Masulipatam | 1868 | Savart | Very strong. |
| Smith | Eden Ridge | 1869 | Arago | None. |
| Pickering | Mount Pleasant | 1869 | Arago | None. |

Prazmowski's conclusions do not agree with his observations, as a radial polarization would have required that the two upper and two lower quadrants should have had the same instead of the complementary tints he describes.

The last column of this table shows how much these observations differ. The Savart in most cases gave a strong polarization, the single observation with the Nicol prism showed none, while only various results were obtained with the Arago. Some again found the polarization most marked near the sun, others at a distance from it. The results also differ regarding the sky around the sun, and the nature of the light received from the moon's disk. So great a diversity therefore showed the necessity of careful preparation for the present eclipse.

### DELICACY OF DIFFERENT INSTRUMENTS.

A number of experiments were made by Mr. Ross and myself with a modification of the polarimeter, with two plates of glass. An unpolarized object was viewed through this instrument, and the plates turned until the polarization became perceptible with the polariscope to be tested. The results were then reduced to percentages by Fresnel's formula. To eliminate index-error, readings were taken on each side of the zero, and the mean used. It was found that the sensibility varied with the size of the object and the intensity of its light. The following series must therefore be regarded as showing comparative rather than absolute delicacy:

Limit of visibility of Savart's bands, 1 per cent.

Limit of visibility of color in Savart's bands, 2½ per cent.

Color first perceptible in a small Arago polariscope with selenite giving red and green images, 5 per cent.

Same with large Arago with quartz giving blue and yellow, 15 per cent.

Nicol prism, variation in light, (or rotating,) becomes perceptible with 10 per cent.

These are the means of series of observations by Mr. Ross and myself.

Another series of experiments were made with a common polarimeter, replacing the Savart by a Nicol prism and the crystal to be tried. The plates were turned until the bands were distinctly visible, equally so with all the crystals. The results were as follows:

| | |
|---|---|
| Savart's plates | 4.2 |
| Calcite 1$^{mm}$ thick cross | 17.2 |
| Calcite 1$^{mm}$ thick rings | 9.6 |
| Hemitrope 3$^{mm}$ thick | 15.1 |
| Doppelspath 3$^{mm}$ thick | 13.0 |
| Doppelspath 5$^{mm}$ thick | 14.7 |
| Aragonite irregular | 15.7 |

A similar series was made some months later using fainter bands.

| | |
|---|---|
| Savart I | 2.0 |
| Savart II, wider bands | 2.5 |
| Spar Hemitrope, black cross | 7.6 |
| Spar Hemitrope, white cross | 6.2 |
| Crystal saltpeter | 8.7 |
| Babinet's wedges | 2.0 |

These results agree very well with the others, and show that Savart's bands give the best results, and that other crystals require from three to four times as strong a polarization to render it visible. The wedges of Babinet described below, however, appear to equal Savart's bands in delicacy. Some allowance should be made for the fact that my eyes are more accustomed to the bands, and therefore perhaps detect them more readily.

Another method was used to compare the biquartz of Prazmowski with Babinet's wedges. The plane of polarization of a beam was measured twenty times with each, and the probable error computed; this would be proportioned to their relative delicacy. The degree of polarization of the beam was first measured by the polarimeter.

| | 5 per cent. | 25 per cent. |
|---|---|---|
| Prazmowski yellow | 1°.45 | 0°.42 |
| Prazmowski violet | 1°.06 | 0°.29 |
| Babinet | 1°.14 | 0°.39 |

From this we infer that the wedges are less delicate than the sensitive tint of the quartz, but more delicate than its complementary yellow color.

From their nature all these observations are necessarily somewhat indefinite and depend in a great measure on the eye of the observer, but they give a general idea of the comparative value of the various instruments.

We next wanted to produce an artificial corona polarized radially, to try our instruments on, and to know what appearance to expect in the solar corona, if its light is of this nature. With the aid of Professor Langley and other members of the party we arranged the apparatus represented in Fig. I.

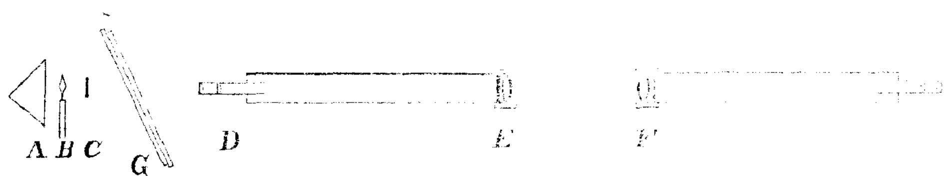


*Fig. 1*

(See also Plate No. 28.) A tin cone, A, was procured and lined with black unglazed cambric, as this substance was found to give the best results. White paper or cloth, while reflecting no more light specularly, added a large amount by diffuse reflection, which being unpolarized marked the effect of the other. A candle, B, was placed in front of the cone and the eye protected from its light by a circular disk, C, representing the moon. On placing the eye in the axis of the cone, light was received and reflected by the cloth in planes passing through the axis, and hence polarized radially. If now one or more plates of glass, G, were inserted in front of the candle we could superimpose a uniform polarization of all the light, and thus imitate all the effects of sky polarization.

As the diameter of the base of the cone was about one foot, it should be placed at a distance of 20 or 30 feet to give it its proper angular dimensions, or, when viewed with a telescope magnifying 30 or 40 diameters, at a distance of three or four hundred yards. As it was necessary to use a darkened room this was impossible, and the common method of using a collimator was impracticable on account of the size of the object. I therefore devised a plan by which we can view any object, large or small, near or distant, with a telescope adjusted for parallel rays, and vary its apparent angular diameter at will. This device is shown in Fig. I, in which, instead of a collimator, an ordinary telescope is used, with eye-pieces attached. The latter D forms a very minute object of A when this is placed a few feet off, and this image is then removed to a distance by F, which acts as a collimator. By slightly altering the focus of D E we render the rays from any object, near or distant, parallel. By changing the eye-piece D or altering the distance of A we readily give it any magnitude we desire. We were thus enabled to test all our polariscopes, whether attached to telescopes or not, on the same object.

We found as a result that when using the Savart it was a matter of extreme difficulty to recognize with certainty the radial nature of the polarization, although the presence of polarized light was shown in a very marked manner, the trouble being to tell on so small an object whether the bands were dark or light-centered. With the Arago, on the other hand, the presence of polarized light was more difficult to detect, but once seen its radial nature was obvious, the top and bottom being of one color, and the sides of a complementary tint. We also found that very good results were obtained with a Nicol prism, especially when it was rotated as a dark band crossing the corona, then turned with it. It should be remembered, however, that in this case the polarization was very considerable and the light feeble, conditions in which the Nicol prism is most valuable. In preparing for the observation of future eclipses I would strongly recommend the use of this imitation corona, and that all the polarizers should be tried on it, as it affords an excellent means of testing their efficiency.

THEORETICAL CONSIDERATIONS.

Two theories have been proposed for the polarization of the sky adjacent to the corona and of the dark disk of the moon: first, that they were polarized radially by reflection from the corona, as when the sun is not eclipsed; and secondly, that being illuminated by reflection from objects beyond the limits of the shadow, they are polarized throughout in a vertical plane, or by refraction horizontally. In the former case, however, the large size of the corona would render the polarization of objects adjacent to it feeble, as may be seen from the discussion given below of the polarization of the corona itself; but even supposing the latter concentrated at a single point, the angle of incidence for the adjacent sky would be so great as to render the polarization very slight. Even at a distance of 2° it would only amount to .03 of 1 per cent., while on the moon's disk, since the angle of incidence would everywhere exceed 89° 52½′, the polarization would be only one two-thousandths of one per cent. As our most delicate polariscopes scarcely show 1 per cent., it would evidently be impossible to detect such feeble polarization. Moreover, radial polarization cannot be observed so near the sun when not eclipsed, although it should then be, if anything, greater than during totality. Of course, this discussion applies only to the sky very near the sun; that at a distance may be polarized radially.

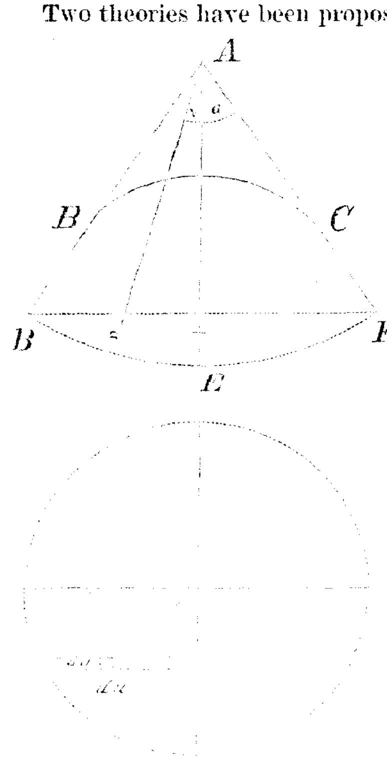

Fig. II

While crossing the Atlantic last November, I obtained a most unexpected verification of the second theory. One morning the sun was barely visible through the fog, and on examining it with the polariscope I found the fog polarized vertically even while near the sun, probably by reflection of the light from the water. Presently the fog cleared a little, and the usual radial polarization appeared; then, becoming thicker, its plane became vertical, so that at one time I could almost trace it to the sun's limb. Of course, there was no change above or below the sun, as there the plane was vertical throughout, but on each side it was sometimes horizontal, sometimes vertical, and at an angle of 45° the bands of a Savart would disappear in one case while they attained their maximum of distinctness in the other. Thus, when clear, the bands, if held vertically, disappeared, and as the sky cleared, the plane of polarization could be seen to swing around to its usual position. The conditions were here the same as during an eclipse, the fog replacing the moon; my own observation of the eclipse of 1869 agrees perfectly with this theory.

The next point to be considered is what amount of polarization we should expect to find in different parts of the corona. Any point as A, Fig. II, receives light equally from all points within the cone, B A C, (neglecting the absorption of the solar atmosphere,) since for the more distant parts the larger area compensates for the increased distance and obliquity. The effect is, therefore, the same as if we had a spherical surface, D E F, with center at A, radiating light to it. Dividing this surface up by two series of planes passing through A, and making angles $u$ and $v$, with A F, and we have the elements $du\,dv$. The amount of light reflected by A from any such element consists of two parts, one polarized in the plane of incidence, the other in a plane at right angles to it. The magnitude of these beams is given by Fresnel's formula—

$$I = \tfrac{1}{2}(A + B)$$

in which the beam polarized in the plane of incidence—

$$A = \frac{\sin^2 (i - v)}{\sin^2 (i + v)}$$

and the other beam—

$$B = \frac{\text{tang}^2 (i-v)}{\text{tang}^2 (i+v)}$$

In the present case we must regard the index of refraction very nearly unity, or $1 + dv$, and hence A is proportional to $\frac{1}{\sin 2i}$ and B to $\frac{1}{\text{tang } 2i}$. These may be again decomposed into two, one polarized horizontally—

$$d^2 H = (A \sin v + B \cos v)\, du\, dv$$

and the second vertically—

$$d^2 V = (A \cos v + B \sin v)\, du\, dv$$

Substituting, since $u = 90° - 2i$,

$$d^2 H = \frac{\sin v}{\cos u}\, du\, dv + \cos v \text{ tang } u\, du\, dv$$

$$d^2 V = \frac{\cos v}{\cos u}\, du\, dv + \sin v \text{ tang } u\, du\, dv$$

As a first approximation, let us consider only the light received from points in the plane of the plates in the upper part of Fig. II; for these—

$$u = 0;\ u' = 45°$$

hence the light is totally polarized in the plane of incidence and—

$$B = 0$$

Hence—

$$d\,H = \sin v\, dv;\ d\,V = \cos v\, dv$$

Integrating between $v = 0$ and $v = a$, and doubling for the two sides of the vertical, we have,

$$H = 2\,(1 - \cos a)$$

and—

$$V = 2 \sin a$$

The former is evidently always the smallest, hence the light is polarized in a vertical plane, (more strictly radially,) the degree of polarization being—

$$\frac{V - H}{V + H} = \frac{\sin a + \cos a - 1}{\sin a - \cos a + 1}$$

In the following table—

| $\alpha$ | $m$ | H | V | $\frac{V-H}{V+H}$ |
|---|---|---|---|---|
| 0° | $\infty$ | .0 | .0 | 100.0 |
| 15° | 43.0 | .062 | .518 | 78.6 |
| 30° | 15.0 | .268 | 1.000 | 57.7 |
| 45° | 6.2 | .584 | 1.414 | 41.4 |
| 60° | 2.3 | 1.000 | 1.732 | 26.8 |
| 75° | 0.5 | 1.482 | 1.938 | 13.3 |
| 90° | 0.0 | 2.000 | 2.000 | 0.0 |

the first column gives $\alpha$, the second the distance from the sun's limb in minutes of arc, the third H, the fourth V, the fifth the degree of polarization in percentages. We see from this that at 6′ the polarization would be only 40 per cent., while at 30″ it would be only 13 per cent. This approximation is the more accurate, since, although the points not in the plane of the paper have a less value of $v$, and hence diminish H relatively, yet this effect is partially compensated by the fact that their polarization being only partial, B is present, by which H is increased.

Returning now to the general case, we have to obtain H and V, from the equations given above, by double integration. Integrating with regard to $v$ we have—

$$dH = -\frac{\cos v}{\cos u}\,du + \sin v \operatorname{tang} u\,du$$

$$dV = \frac{\sin v}{\cos u}\,du - \cos u + \operatorname{tang} u\,du$$

Since for any point on the exterior of the cone B A C we have—

$$\cos \alpha = \cos u \cos v$$

or—

$$v = \cos^{-1}\frac{\cos \alpha}{\cos u}$$

our integral must be taken between $v = 0$ and $v = \cos^{-1}\frac{\cos \alpha}{\cos u}$; hence:

$$dH = -\frac{\cos \alpha}{\cos^2 u}\,du + \frac{\sqrt{\cos^2 u - \cos^2 \alpha}}{\cos^2 u}\sin u\,du + \frac{du}{\cos u} = dM + dN + dO.$$

$$dV = \frac{\sqrt{\cos^2 u - \cos^2 \alpha}}{\cos^2 u}\,du - \frac{\cos \alpha \sin u}{\cos^2 u}\,du + \frac{\sin u}{\cos u}\,du = dP + dQ + dR$$

We have thus six terms to integrate, which give—

$$M = -\int \frac{\cos \alpha}{\cos^2 u}\,du = -\cos \alpha \operatorname{tang} u$$

$$N = \int \frac{\sqrt{\cos^2 u - \cos^2 \alpha}}{\cos^2 u}\sin u\,du$$

making $\cos \alpha = a$, $\cos u = x$,

$$N = \int -\frac{\sqrt{x^2 - a^2}}{x^2}\,dx = +\left(\frac{\sqrt{x^2-a^2}}{x}\right) - l.(x + \sqrt{x^2 - a^2})$$

$$= +\frac{\sqrt{\cos^2 u - \cos^2 \alpha}}{\cos u} - l.\left(\cos u + \frac{\sqrt{\cos^2 u - \cos^2 \alpha}}{\cos u}\right)$$

$$O = \int \frac{du}{\cos u} = l.\operatorname{tang}\left(\frac{\pi}{4} + \frac{u}{2}\right)$$

Hence we have the complete integral—

$$H = -\cos\alpha \operatorname{tang} u + \frac{\sqrt{\cos^2 u - \cos^2 \alpha}}{\cos u} - l.\left(\cos u + \frac{\sqrt{\cos^2 u - \cos^2\alpha}}{\cos u}\right) + l. \operatorname{tang}\left(\frac{\pi}{4} + \frac{u}{2}\right)$$

Treating V in the same way, we have—

$$Q = \int \frac{-\cos\alpha \sin u}{\cos^2 u} du = -\frac{\cos\alpha}{\cos u}$$

$$R = \int \frac{\sin u}{\cos u} du = -l. \cos u$$

On attempting to integrate the last term,

$$P = \int \frac{\sqrt{\cos^2 u - \cos^2\alpha}}{\cos^2 u} du$$

we find that it is an elliptic integral, whose value can, therefore, only be obtained approximately. A development by the binomial theorem gives—

$$dP = \frac{\sin\alpha}{\cos^2 u} du - \frac{\sin^2 u \, du}{\sin\alpha \cos^2 u} - \frac{\sin^4 u \, du}{8 \sin^3\alpha \cos^2\alpha} + \&c.$$

$$P = \sin\alpha \operatorname{tang} u - \frac{\operatorname{tang} u - u}{\sin\alpha} - \frac{1}{8\sin^3\alpha} \int \frac{\sin^4 u \, du}{\cos^2 u} - \&c.$$

Hence—

$$V = -\frac{\cos\alpha}{\cos u} - l. \cos u + \sin\alpha \operatorname{tang} u - \frac{\operatorname{tang} u - u}{\sin\alpha} - \frac{1}{8\sin^3\alpha} \int \frac{\sin^4 u \, d\, u}{\cos^2 u} \Big\} - \&c.$$

of which the other terms are best integrated by series. Having performed this integration and taken proper limits, we should get H and V for a certain point of the corona. We should then strictly consider all other points in the same straight line with the observer, and take the sum of their effects. The approximation given above, however, shows the general result, which is, that if the polarization is produced by reflection according to Fresnel's theory, it should be most marked at a distance, diminishing to nothing close to the sun's limb.

INSTRUMENTS.

The telescope I used was the finder of the 15-inch equatorial at Cambridge. Its aperture was 3 inches, focal length 48 inches, and its mounting equatorial. I had attached to it the eye-piece represented in Figure III, made by Zentmayer, of Philadelphia.

A B is a common positive eye-piece containing a Nicol prism C. At its focus is a slide D, with three holes, into which different polarizing plates can be placed and changed instantly. A B can also be drawn out and a higher or lower power substituted. The whole was arranged so that it could revolve and the angle be measured by a graduated circle E, and index F. One of the apertures in D was left vacant, so that the Nicol prism alone could be used; it would perhaps be better to fill it with a thick piece of plate glass, that the focus might be the same as when the other apertures were used. The second place contained a biquartz, or two plates side by side, one turning the ray to the right the other to the left. When this line of junction is parallel to the plane of polarization, both assume the same color, which is a peculiar violet tint, known as the transition or sensitive tint. Turning it 90° the color of both becomes complementary or dull yellow; in other positions, one is red, the other green. In the third aperture, at the suggestion of Professor Stokes, I placed the quartz wedges used by Babinet, which show bands like those of a Savart polariscope, only reversed, that is strongest when inclined 45° to the plane of polarization,

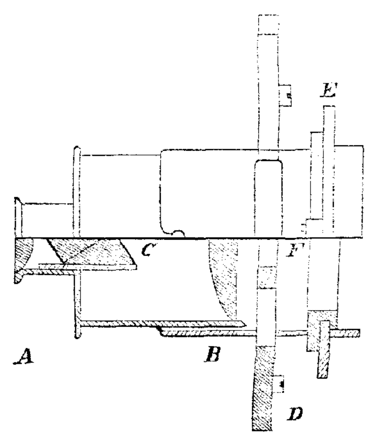

*Fig. III*

and disappearing when parallel or perpendicular to it. I at first intended to use a Savart in this position, but this requires diverging rays and cannot be used with a parallel beam. I also had a cheap 3-inch telescope, by Newton, for a collimator in testing the polariscopes and for determining contacts and general observations. It was suggested by Professor Young that one cause of my not seeing any polarization in 1869 may have been the small size of the corona. He, therefore, proposed that it should be enlarged by placing an Arago in front of the telescope. I accordingly strapped a small French telescope as a finder to my larger one, and slipped a cap on the objective with a double image prism and quartz plate. This arrangement has also the much more important advantage of eliminating the sky polarization; for while the two images of the corona are so far separated that one only is visible, the second image of the sky, distant two or three degrees, overlaps the first, so that all disturbing effect of it is removed, and we have the corona polarization alone.

To measure the degree of polarization a modification of Arago's polarimeter was used, consisting of four plates of glass free to turn and carrying an index and graduated circle which shows the amount of the rotation. The object to be tested is viewed through them with a Savart polariscope, the bands being placed parallel to the axis of rotation. The whole instrument is turned until the bands are perpendicular to the plane of polarization, when they will be white centered, and the plates are then turned until they disappear. From the angle we can tell the amount of polarization present, since it is then just equal to that produced by the plates. We also carried two Arago's polariscopes, one consisting of a double image prism and *quartz* plate placed at opposite ends of a tube of such a length as to give two images of the quartz in contact, but not overlapping. The second Arago consisted of a double image prism and plate of selenite placed close together, and attached to the end of a tube, the further end of which was closed by a cap with a square hole in it.

One other instrument remains to be described, namely, that prepared for measuring the amount of light remaining during totality.

Previous observations of this quantity are extremely vague, and we, therefore, attempted some more accurate measure. A darkened box, A B, Figure IV, was prepared about six feet long.

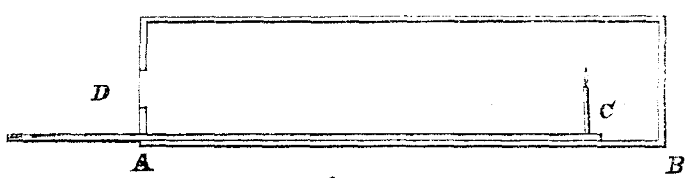


*Fig. IV*

In this was placed a candle, C, on a slider, by which it could be placed at any distance from the aperture D. This slider carried a graduated scale, so that the distance C D was given directly in tenths of an inch. D was closed by a disk of paper with a circle oiled in the center as in the Bunsen photometer. The first difficulty encountered arose from the fact that the light of a candle is so different in color from that of daylight that in no position would the spot disappear. We then inserted a piece of blue tissue-paper between it and the candle, which, cutting off the red rays of the latter, rendered its color more nearly that of daylight. A more convenient method was to use a piece of glazed paper, blue on one side, which gave a spot which disappeared almost perfectly. By this arrangement we can at any time darken a room so that the obscurity shall be the same as that of totality or compare the latter with twilight.

## OBSERVATIONS.

The point selected for our observations in Jerez was the top of the house of Señor Rivero, who kindly placed it at our disposal. It was distant about half a mile from the station of the other members of the party and commanded an excellent view of the surrounding country, especially in the direction where the shadow passed off. The day was cloudy and rainy, but we obtained a tolerable view of first contact and were able to watch the gradual progress of the eclipse. Mr. Ross took charge of the photometer and the larger Arago polariscope, but a few minutes before totality, it was so cloudy that I laid down my instruments, thinking that nothing could be seen with them, and that it would be better to devote our entire attention to the photometer. Fortunately, however, at the moment of totality, the clouds, although still covering the sun, became sufficiently thin to enable us to carry out our original plan, and to obtain quite a good view of the corona. Mr. Ross's observations were made by making the spot disappear, then drawing a line with a pencil across the scale of the photometer, setting the instrument again, drawing a second line, and so on, moving the scale each time. He thus obtained a permanent record of his readings, which were as follows:

| No. | Scale. | Intensity. | No. | Scale. | Intensity. |
|---|---|---|---|---|---|
| 1 | 21.0 | .23 | 5 | 20.9 | .23 |
| 2 | 19.8 | .25 | 6 | 18.4 | .30 |
| 3 | 17.5 | .33 | 7 | 14.4 | .48 |
| 4 | 19.6 | .26 | 8 | 16.6 | .36 |

The considerable variation in these results is doubtless due to the continual change in the clouds drifting over the sun, and probably also to the change in position of the moon. They afford, however, almost the first quantitative measure of the actual intensity of the light during totality, and the ready means of comparing it with twilight or a cloudy day.

He also made an observation with the larger Arago polariscope, holding it so that when looking at a horizontal plate of glass, (that is, when the plane of polarization was vertical,) the right-hand image was yellow, the left-hand one blue. On looking at the corona, the appearance represented in Fig. V, Plate No. 28, was seen, in which horizontal lines represent yellow and vertical blue. He says: "The appearance of the corona was perfectly white, that of the sky around it the opposite of that obtained with a horizontal plate; that is, the blue was on the right. The inference to be drawn from this would be, that the plane of polarization of the sky surrounding the corona was horizontal. The colors were faint but unmistakable. I did not note the appearance of any color on the surface of the moon. The color of the sky in the right-hand image was a dull bluish-purple, the other a dull yellow."

My own observations were, however, quite at variance with this. I first used the smaller Arago with a plate of selenite, which gave red and green images, but since it is impossible to grind selenite to as true a surface as quartz or glass, objects seen through it are a little indistinct, as when seen through mica or uneven window-glass. I found, however, the two images of the corona distinctly colored, the right-hand one red above and below, and green on each side; the other with these colors reversed, showing a radial polarization; the sky polarization was comparatively faint. I next pulled the prism and selenite, which were fastened together, out of the tube, and repeated the observation; the sky polarization was thus eliminated, as two images distant 3° were superimposed. The same result was obtained as before, showing that the effect could not but be due to sky polarization. I then returned to my telescope, in which I had adjusted my bi-quartz and the low power eye-piece. With this I got less conclusive results. The image was dimmed by the clouds, though not sufficiently to prevent the colors from being distinctly visible. On attempting to record them, however, they seemed to be continually changing, and this was probably in reality the case, as we know that a clear sky is strongly polarized, while, when cloudy, no signs of this phenomenon can be detected. Hence, every cloud crossing the moon's disk would change the colors. I then attempted to see if at any time I could detect the colors due to radial polarization, that is, green above and red below, and am very confident that at one time these colors were present. The colors were distinctly, though faintly, visible over the moon's disk and uniform on each side of the line of junction of the quartz, showing that the moon's disk was polarized not radially, but in the same plane throughout. These observations took some time, and when completed I looked at the corona with a Savart not attached to a telescope. This showed bands on the sky which were much stronger on the corona, and when turned so as to disappear on the former, still remained visible on the latter; thus showing the independent polarization of the latter. Totality being now nearly over, I watched for the passage off of the shadow. I failed to see it, however; probably owing to the presence of the clouds, which rendered it difficult to tell when totality ceased.

I noticed in a very marked manner the chill often described during totality, which surprised me, as I expected that the clouds would prevent much radiation. Although the thermometer stood at 62° at first contact, during totality the cold rendered my hands numb and caused my eyes to water. After totality the clouds became so thick that no further observations were possible.

The only observation of importance during the partial phase was that, shortly before totality, I examined the sky close to the sun and found no traces of polarization, which agrees with all the other observations in supporting the second theory of sky polarization described above. I also noticed that just before totality the upper point of the sun's crescent was cut off by a mountain in the moon.

### CONCLUSIONS.

The polariscope is an instrument so sensitive to the presence of clouds that it does not seem safe to draw any decided conclusions from these observations. The principal point to be discussed is the want of agreement with the two Arago polariscopes used. The instruments are so easily used and the effects are so striking, it seems scarcely possible that any mistake in observing could be made with them. I used the larger one in 1869 and obtained the same result then that, Mr. Ross did, in the last eclipse. My recollection of it is so distinct and so utterly unlike what I saw with the small Arago this year that I am confident it cannot be a mere error of observation. The next question was whether it might be due to a defect in the instrument. But it was tested and found to be in good order beforee ach eclipse, and has been frequently used for the last two years, always giving good results. Moreover, while showing no polarization in the corona it rendered that of the sky very preceptible, which proves that there is no defect in the instrument. Though less delicate than the other Arago, it surely ought to have shown the marked polarization evinced by the smaller instrument. The only other possible explanation seems to be some peculiarity in the condition of the light which would affect some instruments and not others. The colors in the two instruments are produced in entirely different ways. In the larger, which contains a plate of quartz, it is due to the unequal rotation of the plane of polarization of the rays of different colors. In the smaller Arago, on the other hand, the colors are produced by a plate of selenite, in which the different rays having different wave length are cut off unequally.

A theory presented itself which at first seemed quite plausible. The spectroscope shows that the light of the corona is in a great measure at least monochromatic. Now the polarization of such light can be detected by a Savart or other instrument showing variation of intensity, but not by an Arago or instrument showing color. To prove this I produced an image of a soda flame by reflection, which was strongly polarized. Viewing this with a Savart the bands were strongly marked; the light varied with a Nicol prism, but no effect was produced on viewing it with an Arago. The polarized light of the corona, however, is doubtless that part which is not monochromatic, and for various other reasons this theory fails. There still remains, therefore, an unexplained disagreement in the observations with different Arago polariscopes, and it is to be hoped that in future eclipses a variety of these instruments may be used, some with quartz, others with selenite. I have only one other suggestion to make in future observations, namely, placing at the diaphragm of a large portrait camera a double image prism and strapping it to a telescope mounted equatorially; we should thus obtain a permanent record of two images of the corona, one polarized horizontally, the other vertically; if they were polarized radially the former would be comparatively faint above and below, the other on the sides. Since the two images would be in other respects precisely alike, we should have an excellent means of permanently recording any polarization of the corona while that of the sky, for reasons given above, would be neutralized.

Respectfully submitted.

EDWARD C. PICKERING.

Professor BENJAMIN PEIRCE,
*Superintendent United States Coast Survey.*

WILLET'S POINT, NEW YORK HARBOR,
*March* 9, 1871.

SIR: I have the honor to submit the following report of my operations with the expedition sent to Spain under your orders by the United States Government to observe the solar eclipse of December 22, 1870.

Having reached Jerez December 11, I was occupied previously to the 22d in making a topographical sketch, which I inclose, of the farm occupied as an observatory, and, when the weather permitted, in observing stars with the sextant for latitude.

The topographical sketch was made by the method of "foot reconnaissance" used in the engineer department of the Army, the instruments employed being a common box-compass, protractor and scale; the distances were measured by pacing. The variation of the needle was measured as carefully as the instruments at hand would permit from the meridian line established by Mr. Dean, and was found to be about 19¾° west. No contours are shown, the ground being so flat that those obtained with the hand-level would lend no additional value to the sketch. A plan of the buildings used for the protection of the instruments is given on a larger scale. In making this plan a small Casella theodolite and a tape-line were used. The house from the top of which observations of the eclipse were taken with the lighter instruments was situated about three-eighths of a mile north-northwest from the barn. Its occupation was determined upon too late for the ground upon which it stood to be introduced into the sketch. Plate No. 28.

In observing with the sextant I was aided by Professor Langley and Mr. Gannett, who kept the record. The weather was not favorable, and I was unable to make as many observations on south stars as I desired. Sufficient were obtained, however, to show that the eccentricity of the instrument, if any, was very slight. The site of the observations was a few feet south of the transit observatory. The chronometers were unpacked on the 13th. The evenings of the 13th, 14th, and 15th were cloudy. On the 16th I was able to observe Polaris. Clouds again on the 17th and 18th. On the 19th Polaris was observed, and on the 20th Polaris and $\beta$ Orionis. The error of the chronometer was furnished each evening by Mr. Dean, who obtained it from observations with the transit instrument. The refraction correction was obtained from observations with a pocket aneroid barometer, and pocket thermometers. The results are shown in the following table:

| Date. | Star. | No. of observations. | Resulting mean latitude. | Probable error. |
|---|---|---|---|---|
| | | | ° ′ ″ | ″ |
| December 16. | Polaris. | 30 | 36 41 49.3 | ± 1.68 |
| December 19. | Polaris. | 40 | 36 41 52.1 | ± 0.24 |
| December 20. | Polaris. | 10 | 36 41 45.5 | ± 2.04 |
| December 20. | $\beta$ Orionis. | 23 | 36 41 45.4 | |

Combining these results by weights I have for the adopted latitude of the transit observatory

$$36° \ 41' \ 49.''3$$

with a probable error of $\pm$ 0.″66.

During the eclipse my duty was to observe the general phenomena and structure of the corona. For this purpose I was provided with the comet-seeker from the Harvard Observatory, having an aperture of 4.5 inches and magnifying power of 30, mounted on a solid wooden tripod. I was stationed upon the top of the house above referred to.

From the time of first contact the sun was frequently obscured by passing clouds until about a minute before totality, when they broke away and left a clear view of the eclipse. This clear view lasted about two-thirds of totality. Just before the final disappearance of the sun the thin crescent of light was broken into fragments, in no manner resembling what have been described and sketched as "Baily's Beads." Near the extremities of the crescent these fragments were so short as to appear almost like points, while at the center a considerable arc had but one break in it when it vanished.

A halo appeared about the moon a few seconds before totality, and as the sun disappeared the corona shot out in all its glory. Surrounding the moon's disk and immediately adjacent to it there was a bright light of varied height and of regular but blurred outline. Where the sun was last seen this light arose to a height of about 4′. At the opposite side it was barely visible, while halfway between it rose to about 2′. These heights are merely approximate, the light fading off so gradually that it was exceedingly difficult to fix its limit. As the eclipse progressed it became lower on the first side, increased in height on the opposite side until the sun appeared and then vanished with the rest of the corona. For want of a better name I shall call it the *glow*. It resembled the brief trail of bright light left by the setting sun on a clear day. It undoubtedly appertained to the sun. Its gradual unveiling on the one side and obscuration on the other settle that point.

Outside of the *glow* streamed forth the radial portion of the corona. To keep a distinction I shall call this portion the streamers, and when using the word corona shall refer to the glow and streamers, collectively. The streamers extended generally about 15′ in height, though they were considerably shorter, say 12′ high, in the direction of the sun's axis. The intervening dark lines radiated from the moon's center and extended from the outer edge of the corona to the *glow*, where they were lost in the brighter light. These dark lines were well marked, clearly visible to the naked eye and straight, except in those portions where the photograph shows openings. Even here I saw no curves, but an amateur observer stationed near me saw them. I had unfortunately selected the opposite side of the corona for my special scrutiny. The streamers did not alter their relative positions but frequently flashed out at greater length and with brighter light, not unlike the flashing of the aurora borealis. For a moment I thought this might be due to passing clouds, but the waves flashed constantly from the center and this fact caused me to change my opinion. The general boundary of the corona was an irregular, jagged line, though it was impossible to give it a definite outline on account of the flashing and the gradual fading off of the light at the exterior. This vagueness and changing of outline will account for the failure of the attempt made by an amateur observer to trace an image of the corona thrown upon ground-glass by Professor Young's comet-seeker.

The color of the corona was a silver white, with a rosy tint near the moon's disk tinging the *glow* and the inner portion of the streamers.

The protuberances were numerous, but I was unable to detect any relation between them, and the structure, shape, or dimensions of the corona.

The effects of the phenomenon upon animate nature were what have often been described, and have no bearing upon the scientific objects of the expedition.

Very respectfully, your obedient servant,

O. H. ERNST,
*Captain of Engineers, United States Army.*

Professor JOSEPH WINLOCK,
*Cambridge, Massachusetts.*

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*Notes to accompany sketch.*

At the commencement of totality the corona appeared to consist of straight rays tolerably evenly distributed; after an interval of about 10 seconds, however, two bundles of curved rays appeared distinguishable from the other parts by a rather greater length, and without any definite limits. The remaining portions seemed to extend about half the diameter of the disk, all round. The tint of the corona was a light grayish-blue, and was darker over the prominences.

Between the curved portions a bright prominence was seen of branched shape and distinct form. On the right upper surface a brilliant corruscation formed the distinguishing feature, in length about one-fifth of the circumference, but of inconsiderable width; there were also three other sharply defined prominences.

The prominences appeared coincident in duration with the totality; the corona, however, seemed to continue a short time longer, no estimation of which could be made owing to the clouds.

The effect on the horizon of the eclipse could not be seen owing to the clouds, these appearing of a dense purple with intervening horizontal streaks of a bright orange. The landscape including the town, as seen from the Recreo Station, was in intense shadow. During the totality the shadows of the surrounding objects were peculiarly distinct.

JOSEPH C. GORDON.

JEREZ DE LA FRONTERA, *December* 22, 1870.

# APPENDIX No. 17.

CHANGES OF ELEVATION AND AZIMUTH CAUSED BY THE ACTION OF THE SUN, AT STATION DOMINGUEZ, CALIFORNIA.

UNITED STATES COAST SURVEY STATION DOMINGUEZ,
*Los Angeles, California, February* 21, 1870.

DEAR SIR: I send herewith a sketch exhibiting the position of the azimuth station at San Buenaventura, upon the edge of the bluff forming the southwest face of the Santa Clara plains.

In my letter of January 12, I mentioned the peculiarities exhibited by the expansion of the bluff; and now state them more particularly.

1. The bluff is about one-third of a mile from the ocean beach, and the space between them is a low flat, which is partly covered by water in the rainy season, the lowest part of the flat being 5 or 6 feet above the sea at low water; while the narrow line of sand-dunes along the shore is about 13 feet above the flat.

2. The bluff, as indicated by the contour lines, is quite steep; composed of sand with a slight mixture of clay, and sufficiently hard to require the pick to remove it. It is little worn by water-courses, and the top, formed of a layer of "*adobe*" soil, (tenacious black clay,) is not worn at all. In dry weather this adobe layer is a hard compact cake. The stratification of the bluff exhibits two strata of coarse sand and boulders at certain parts, and all are nearly horizontal. The surface of the bluff is 75 feet above the ocean. For the first 30 or 40 feet below the top the slope is about 1 to 1. Upon that part there is little or no vegetation; but upon the lower slope there is, in season, a heavy growth of wild mustard.

3. The season had been remarkably dry, probably less than one inch of rain in two showers a month apart. I think there had been but these two showers since March, 1869.

4. When commencing horizontal angles in the morning at sunrise, I have found the instrument as much as 45″ out of level, the western side being low. After leveling, some change would take place during the observations—say two hours—the west side growing higher.

5. When commencing the post-meridian observations, about 1½ hours before sunset, I have found the instrument as much as 45″ out of level; the western side being high.

6. When commencing the azimuth observations after sunset, the instrument would be found out of level; western side falling. After leveling, and during the observations for azimuth, the level of the instrument would change again, and amount to as much as 15″ in three hours, the western side generally falling.

7. During the azimuth observations the promontory-like point of bluff would twist irregularly in azimuth as much as 18″. Similar results were exhibited during the ante-meridian horizontal angles, ranging as high as 10″ when the observations were prolonged three hours after sunrise.

8. The range of temperature at the station was from 40° to 80° in the shade, with a predominance of bright, clear days.

9. Upon cloudy days the minimum of change of level was experienced, and cloudy weather, combined with varying winds, produced irregular effects. Upon some days when much change was expected, less than the maximum would be found.

10. Systematic observations were not made to determine all the peculiarities of this heat-level movement, on account of regular duties absorbing all my time. A long series would be necessary, involving a large range of subjects.

11. The abnormal results of the azimuth observations and the horizontal angles occasioned me much axiety at first. Although familiar with similar changes in some of the fixed observations, these were so great that I was at a loss to account for them. I examined the foundation, tested

my instrument-stand, &c., &c., and only about the third night became satisfied that the effects were wholly due to the heat of the sun pouring, in a clear day, for six or seven hours upon the face of the bluff, which in turn radiated the heat at night.

12. The changes of level and azimuth in my transit confirmed my judgment, although they were not so strongly marked, the instruments being 30 feet farther from the edge of the bluff. Upon changing the positions of the meridian instrument and zenith telescope to a point about 152 yards north, and 102 yards from the edge of the bluff, these changes ceased, but those at the station for azimuth observations continued.

Asking your indulgence for so long a report upon an incidental subject,

I am, very respectfully, yours,

GEORGE DAVIDSON,
*Assistant United States Coast Survey.*

Professor BENJAMIN PEIRCE,
*Superintendent United States Coast Survey, Cambridge, Massachusetts.*

# APPENDIX No. 18.

## ON THE PROBABLE EFFECT OF EXTENDED PIERS IN MODIFYING THE CHANNEL FACILITIES OF SAN FRANCISCO BAY, NEAR YERBA BUENA ISLAND.

BROOKLINE, MASSACHUSETTS, *February* 5, 1871.

DEAR SIR: In the winter of 1869-'70, I had the honor, at your request, to draw up an opinion concerning the physical effects likely to follow the construction of a causeway or bridge from the Oakland shore of San Francisco Bay to the island of Yerba Buena. This opinion was handed to you with the statement that its value depended on the magnitude of the elements of the problem to which it referred, and that I was without personal knowledge of these.

A visit, with yourself, to the locality in July last, and a series of careful observations continued afterward by your direction, have furnished me with measures of the elements above referred to, and these I now transmit to you as addenda to the opinion.

The channels which separate the island of Yerba Buena from the city shore upon the one hand, and from the Oakland shore upon the other, are very unequal in magnitude and in the parts they sustain in the physical system of San Francisco Bay. I have so arranged the elements of these channels that they appear in contrast, side by side, in the subjoined table.

| Elements. | Main channel. | Yerba channel. | Ratio. | Remarks. |
|---|---|---|---|---|
| Width on surface | 2,777 yards | 5,160 yards | 1 : 1.9 | On our line of cross-sections. |
| Width between four-fathom curves | 2,770 yards | 1,246 yards | 2.2 : 1 | |
| Maximum depth | 24 fathoms | 8¼ fathoms | 3 : 1 | |
| Area of section | 74,970 square yards | 27,764 square yards | 2.7 : 1 | At half-tide. |
| Mean velocity of stream | 0.9 knots | 0.43 knots | 2.1 : 1 | From shore to shore. |
| Passing volume | 137,000,000 cubic yards | 24,000,000 cubic yards | 5.7 : 1 | Mean per hour. |
| Maximum velocity (observed) from shore to shore | 2.94 knots | 1.4 knots | 2.1 : 1 | |
| Maximum velocity (observed) in Thalweg | 3 knots | 2.24 knots | 1.3 : 1 | |

Observers, Messrs. Mitchell, North, and Le Conte; H. L. Marindin, computer.

The surface width of the Yerba channel is nearly double that of the main channel, but a comparison of the pathways for deeply-laden ships reverses this relation. The sectional areas, compared at half tide, give to the main avenue nearly three times the magnitude of the other; and the comparison of passing volumes shows that, as a conduit, the former performs nearly *six times as much service as the latter*. The maximum velocities in the *thalweg* are not widely different in the two cases, but the rates from shore to shore at times of maximum and mean velocities are double as great for the main channel as for the other.

It appears from these data that the complete closure of the Yerba Channel would augment the velocity in the main channel only 12 per cent. If we confine our attention to the portion of the present railroad pier which serves as a bridge only, that is to say, if we take the present wharf, exclusive of the portion containing slips and ferry-berths, we find from our observations that the reduction of velocity caused by the piles is 15 per cent., from which we may safely conclude that if the bridge were extended with similar construction to the island, the loss of passing volume would be less than 4,000,000 cubic yards, and the augmentation of the velocity in the main channel only 2½ per cent.

The south basin of San Francisco Bay is the recipient of no large fresh-water supplies even during the rainy season. The land waters of nearly two-thirds of the State of California find their way into the Sacramento and San Joaquin Rivers, which unite at the head of Suisun Bay, and thence pass through Karquines Straits into San Pablo Bay, which opens into the north basin of San Francisco Bay.

I can think of no possible influence that the proposed bridge can exert upon the outer bar, since no essential reduction of the tidal volume of the bay is involved and no alterations of the tidal epochs are likely to occur.

Very respectfully, yours,

H. MITCHELL,
*Chief Physical Hydrography, United States Coast Survey.*

Professor BENJAMIN PEIRCE,
*Superintendent Coast Survey.*

# APPENDIX No. 19.

## ON THE PHOSPHATE BEDS OF SOUTH CAROLINA, BY PROFESSOR N. S. SHALER.

### PHYSICAL GEOGRAPHY OF THE PHOSPHATE REGION.

The physical geography of the area occupied by the phosphate beds is so important, not only to a proper understanding of the history of their formation, but also to a right appreciation of their economic value, that it will be well to set it forth briefly before we consider the beds themselves.

The coast of the United States, between the parallels of 25° and 35° north latitude, forms a shallow and very regular westward curve. The depth of this bight is about two hundred miles, and the width of the opening measured from Cape Hatteras, its northernmost, to Cape Florida its southernmost point, is not far from six hundred miles.

The land which bounds this great indentation is quite level for a distance of some tens of miles from the shore, rarely rising more than 75 feet above the tide level within this belt. The characters of the shore along this great bay of the Carolinas* varies very remarkably, considering the little variety of vertical relief found there. From Cape Hatteras southward, for a distance of about two hundred miles, the shore is bordered by a peculiar series of low islands, disposed in the fashion of a barrier reef. Along this whole shore the sands which comprise the outer islands seem to be in constant movement, the gaps between the islands changing their positions from year to year. The observations of the Coast Survey have given very valuable data for the study of these peculiar reefs, but it is not necessary for us to examine their history. South of Cape Fear we pass beyond this system of barriers and come upon a section of shore which differs in no important regard from the usual type of low shore on which the sea is slowly gaining. This second section of the bay of the Carolinas has a length of about one hundred miles, extending from Cape Fear to Cape Roman. The whole coast from Cape Hatteras to Cape Roman forms three great indentations. The northernmost of these, sometimes known as Raleigh Bay, is entirely formed by the narrow ridge of the sand-reef which separates the ocean from the broad water of Pamplico Sound. Immediately on the south of Raleigh Bay lies Onslow Bay, which shows along the whole coast-line the same structure which we find in Raleigh Bay, but somewhat less distinctly. South of the southern point of this bay we find less and less of this barrier reef, until, as before remarked, the coast returns to the ordinary type of a low wasting shore. Continuing southward beyond this monotonous coast we find, at about twenty miles north of Cape Roman, the beginning of a new type of coast. Instead of barrier reef, with a considerable expanse of open water between it and the shore, the coast begins to be penetrated with long tide-water creeks which cut up the shore region in an irregular manner. From Cape Roman to Charleston this character becomes more and more pronounced. From Charleston southward as far as the mouth of the Saint John's River, in Florida, a distance of nearly two hundred miles, the coast for a depth of from five to twenty miles is intersected by these arms of the sea to such an extent that at many points the islands form two or three successive tiers. These tide-water channels are to be counted by thousands, and vary from a few feet wide to sounds like the Broad River at Port Royal, which has a width of two or three miles. The general appearance of such a shore is not unlike what is seen on the northern part of the coast of this continent within the limits of what has been termed the fiord zone. The complication of outline along the Carolina and Georgia sea-border quite equals anything which can be found on the shore of Maine or Labrador. A careful comparison of the details of the topography of any region in the fiord zone with what we find on this southern coast will show some essential

*Not being able to find any name for this remarkable feature of our continent, I have ventured to give it this one, in order to avoid the difficulties arising from the want of designation.

differences. The maps of the Coast Survey for the island region of Maine, if compared with those of the sea islands, show the features in question very clearly, and the reader is referred to them for the character of the topography of these areas, if he has not had an opportunity of studying it in the field. The most important of these differences is that the main channels of the fiord regions always run perpendicular to the shore, while in the sea islands the channels approximately parallel to the coast are more numerous than those which are perpendicular to it. It is evident that no such scouring as is brought about by glacial streams could have excavated the tortuous channels of the sea-island region, for, to have produced such water-ways, the ice currents would have had to move parallel to the shore, which is clearly impossible.

It is by no means easy to understand just how this peculiar complication of the shore has been produced, but there are some features in its structure which seem to throw a little light upon the question. Throughout the sea-island region the attentive observer may see that the surface of the ground is disposed in long, wave-like undulations, the summits of which are generally parallel to the shore. On the innermost of the islands the action of the weather has partly obliterated these reliefs, but over a large part of the territory they are still quite conspicuous.*

On Saint Helena Island they are peculiarly distinct, for the valleys between the summits of the ridges, though they are only a few feet deep, are still depressed enough to convert their bases into swamps, so that the alternation of upland and morass in parallel lines characterizes a large part of the surface of this and the adjoining islands. It is clear, on even a casual inspection, that these reliefs are not the product of aërial erosion; their channels are rarely occupied by streams: indeed, one may travel for days among these islands without seeing any indications of subaërial erosion, except from tidal currents wearing away some low cliff. There can be no doubt that this contour of surface is due to submarine forces, and that the essential features of the topography of this region were impressed upon it before it came out of the sea. Something of this same character of surface may be found beneath the level of the ocean along this coast, though it is at no point so clearly traceable as on the surface of the islands. There can be little doubt that these ridges and furrows are due to the run of tidal currents along the shore. There seems to be a tendency in streams not bounded by resisting banks, such as the tidal streams which course along a shallow shore, to arrange the material they sweep over in long ridges. Such a stream does not always press equally upon its floor, but is apt to have a banded character, or to have a form which may be compared to several streams flowing side by side and closely joined with each other. Just what this is owing to it is not easy to say, but it seems not altogether improbable that the peculiar alternate strips of hot and cold water noticed in the Gulf Stream by the officers of the Coast Survey, may be due to the same or a related cause. The action of currents of air upon incoherent vapor in the atmosphere forming the banded clouds, called by sailors *mares' tails*, may possibly be due to the same tendency.

In order to understand just how the sea acted upon this surface as it began to be lifted above it, it must be noticed that although the tides at Cape Hatteras or Cape Florida are not more than two feet in height, they steadily increase as we go nearer to the center of the bay, until at Fort Pulaski, at the mouth of the Savannah River, they are over seven feet in height. This heaping up of the tide in this bay may be entirely due to the usual action of converging shores upon the tidal wave which flows into the bay they form, though it does not seem as if the indentation was sufficiently deep to produce so great an effect.

If we go back to the time when this shore began to emerge from the sea, it will be seen that where the tide was of considerable height it would tend to sweep around the low islands formed by the upper part of the ridges before described, and to dig out the incoherent sands which formed the bottom of the troughs between them. As the shore gradually rose higher these water-ways would be more defined; but if there was an extensive tide-water surface left, the scouring action would be quite decided, and these channels might in time acquire considerable depth.

* I am much indebted to Assistant C. O. Boutelle for information on many points connected with the topography of this region, both subaërial and submarine, and especially for having called my attention to these parallel ridges on Hilton Head Island.

A careful reconnaissance of the shore between Capes Hatteras and Florida will show the observer that the sea-island topography begins where the tide rises above about four feet, and becomes more and more marked as we go toward regions where the tide becomes higher and higher, or, in other words, that in a general way the amount of complication of outline of the shore-line is proportionate to the height of the tide.

GEOLOGICAL HISTORY OF THE SOUTH CAROLINA COAST REGION.

The physical geography of this region affords the key to its geological history, or to that portion of it, at least, which has given it the character it has at present. But to understand the more remote history of this region we must go back to a time when the shore-line was at least two hundred miles west of its present position. At the close of the Cretaceous era the shore of this southeastern border of the continent lay near to the base of the Alleghany Mountains. The uplifts at the close of the Eocene probably carried the shore-line some distance to the eastward, but just how far it is not easy to say, as subsequent wearing action has destroyed a part of the record. The elevation which closed the Miocene seems to have been far greater than that which came at the end of the preceding period. It appears as if the shore-line must have come at some points, especially on the southern part of South Carolina, nearly as far east as the present coast.

The last considerable change of level which this shore has experienced came at the close of the Pliocene era. It seems likely that this uplift carried the shore-line much to the eastward of its present position. The whole of the sea-island belt is being worn away by the ocean at quite a rapid rate. The scouring action of the powerful tidal currents which flow through the fiords between the islands, tears away a great deal of the materials over which they sweep. Along the whole sea-island belt from Winyah Bay, just north of Cape Roman, to the mouth of the Saint John River, in Florida, this erosive action has resulted in the production of a broad, slightly submerged table-land, having an average width of about eight miles and an average submergence of about three fathoms. This table of sands is very well shown on the sailing chart of the United States Coast Survey, sheet 3d. The outer part of this bank probably marks the position of the shore at the close of the last uplift—that which created the sea-island region. We shall soon see reasons for supposing that this must have been an exceedingly recent occurrence in the geological sense of that word. Wherever one of the great tide-water streams, such as the Edisto, the Coosa, or the Broad River, debouches into the sea, the coast chart shows that the sands swept out by it have built a delta which reaches beyond the table-sands, and some distance out into the deeper water beyond.

It is very probable that the coast-line was once much farther out to sea than the border of this three-fathom-deep shoal would indicate. The discovery, by Assistant Boutelle, of the Coast Survey, of an entire skeleton of an elephas primigenius (?) on the left bank of Beaufort River, near its entrance into Broad River, besides being the most interesting feature in the paleontology of this region, throws some light on this matter. On visiting this locality, which is situated at the point marked 11, on the reference-map, (sketch No. 24,) I found fragments of the same skeleton, and the shells of species of Lymnæa and Paludira, which showed that the skeleton had been preserved in a fresh-water deposit. A glance at the position of the locality will show that the sea must have made a considerable gain upon the land since the time when a fresh-water morass could have existed at this point. If the reader will attentively notice the way in which the Gulf Stream runs after it leaves the straits of Florida, he will perceive that it is thrown with great violence against a part of the coast of the bay of the Carolinas. Its current, with a velocity of two to four miles per hour, strikes against the bottom of the sea in 31°, where the water has a depth of only one hundred fathoms. From this point nearly to Cape Hatteras, or for most of the length of the bay of the Carolinas, this stream probably touches the bottom on its inside border.

There can be no doubt that this stream must exercise a certain wearing action against this part of the slope of the continent. A river having the velocity of the Gulf Stream at this point, or a tidal current such as may be observed in our harbors, is capable of taking up and removing considerable quantities of detritus. Whatever erosive force the Gulf Stream may have at present, there is a great probability that in the immediate geological past its action on this shore must have been quite powerful. It has been clearly shown by Professor Agassiz that the Florida coral reefs are but the last stages in the building of that great natural breakwater, and that the whole peninsula is probably the product of the work of the existing species of polyps and acalephs, working during the last geological period. If this be so, then it follows that before the erection of the Florida mole the Gulf Stream must have swept against the shore of the Carolinas in a more direct way than it does at present. The removal of the southern half of Florida would certainly increase the violence with which the stream presses against the Carolina shore. There is, furthermore, no doubt that the region swept by the inner edge of the Gulf Stream is composed of materials calculated to wear very rapidly when submitted to the action of a current of water. Although these considerations are not calculated to give us any decided assurance concerning the part which the Gulf Stream has played in the erosion of this shore, they still make it probable that it has had no unimportant share in the shaping of the coast.

It may be remarked, in passing, that there seems to be no clear evidence of recent subsidence on this coast. I am satisfied that the many facts which seem to indicate such action, and which have even deceived the remarkably acute Sir Charles Lyell, are really to be attributed to a variety of minor accidents, such as the undermining of the coast by the action of the waves, or to the rotting away of a considerable thickness of vegetable matter beneath the surface of the ground. This view of the meaning of these supposed evidences of subsidence is ably defended by Professor Tuomey in his report on the geology of South Carolina.*

## THE GEOLOGY OF THE PHOSPHATE BEDS.

The effort to identify accurately the formations of North America with those of Europe has led in some cases to the hasty use of the names which have been applied to certain beds in the European sections, to designate American rocks.

In the nomenclature of the South Carolina beds, we have what seems to be an instance of this confusion of names. In the largest work which has yet been published on the geology of this region, the "Report on the Geology of South Carolina, by Mr. Tuomey," the Tertiary rocks of the State are divided into Eocene, Miocene, and Pliocene, to suit the then newly proposed classification of Sir Charles Lyell. The Eocene Tertiary is described as occurring in two different regions in two widely varying conditions. In the western part of the State the section shows, first, beds of sandstone and grit; second, beds of sand, gravel, and colored clays; third, siliceous clay; fourth silicified shells; fifth, beds of sand and iron ore. In the shore region a great thickness of tolerably uniform marls is assumed as the equivalent of this varied formation, the apparently not unreasonable view of Mr. Tuomey being that the difference in the position of these two regions relative to the shore has caused the difference in the physical character of the beds. The organic contents of the supposed identical beds in the east and west regions of the State are as varied as are their physical features. The fossils of the buhr-stone, or western beds, named in the list of Tuomey, are almost all Gasteropods and Lamellibranchiates. The general character of these shells may be accepted as rather more like the Eocene of Europe than any other member of the Tertiary series there, but their horizon has been determined, not by the comparison of the resemblances of the species, but by the fact that all the species found in this association are extinct. But although there is no apparent reason to question the position assigned to the buhr-stone formation, there must be doubt concerning the position of the beds of the shore region, which are placed as contemporaneous with it. We have in the Santee beds an assemblage of fossils very different from those occurring in the buhr-stone, and containing species, such as the Zeuglodon cetoides, differing widely from anything found in the latter formation.

Still further to the east we have again in the marls of the Ashley and Cooper Rivers other physical conditions, and an assemblage of fossils which it is difficult to believe could have been deposited in the same geological period as buhr-stone fossils. Nor can we suppose that the one

* Dr. Ravenel thinks that he has recognized the phosphate beds at the depth of about 60 feet below the surface at Charleston. If this should be verified, we would be compelled, as will be seen hereafter, to suppose that after the formation of the phosphate bed under atmospheric agencies, the shore had been depressed to the depth of at least 60 feet below its present position. It would be difficult to account for such a great subsidence at this point, while beds at a distance of nine miles to the westward have not changed their position.

series of rocks was deposited far inland, and the other near shore, for in the Ashley beds, as remarked by Mr. Tuomey, the character of the fossils shows clearly that they could not have been deposited far from the sea-border.

There does not seem the same reason for questioning the identity of the Santee beds, and those found along the borders of the Ashley and the Cooper Rivers, that there is to doubt the identity of the age of the latter beds and the buhr-stone. The identity of the first-named beds does not seem to be sufficiently proven; the contemporaneous origin of the last named is at first sight so improbable that it cannot be accepted without direct proof, which has not been presented. The level character of a large part of the surface over which these beds in question extend makes it extremely difficult to trace by natural sections the relations of these several series of rocks. The paleontological evidence not being clear, the matter must remain in some doubt until we have artificial sections, which artesian wells, tapping the abundant subterranean waters of this region, will doubtless soon give.

Overlying the Santee beds and the beds of the Ashley and Cooper Rivers, there are found at various points marls which are probably to be regarded as of a Pliocene age. This is the age assigned to them by Mr. Tuomey, and if we must make a division of the Tertiary section, assigning a part to each of these three names, Eocene, Miocene, and Pliocene, there seems no reason to protest against the term. The extent of country covered by these beds is so small, and their disposition so irregular, that it seems necessary to suppose that a great amount of erosion has acted upon the surface, and that only patches of the formation as it once existed have remained to the present day. These beds are of great value to us, however, merely as evidence of long-continued exposure of the low lands of this part of the Atlantic shore.

The bed of phosphate of lime which we have been preparing to study lies immediately on top of the "marls of the Ashley and Cooper Rivers," as they have been generally termed, though these beds are not limited to the basins of these streams. The whole of the workable material lies in a single bed, from six inches to three feet in thickness. Although it varies in its chemical and fossil components, it retains everywhere certain marked features. It is always more or less nodular; the nodules vary much in size, some being no larger than a pea, some a foot or more in diameter. These nodules contain, generally, one or more fragments of shells or corals, apparently all Eocene species, which seem to have been the aggregating points of the matter contained in the nodule. So far as my knowledge goes, there have been few, if any, nodules found containing traces of vertebrate remains. Many of the nodules show traces of wearing, not exactly what would be expected from their being rolled as by a stream, but the style of wear which comes from being stamped and trodden on. The appearance of the worn surfaces reminds me of that seen on fragments of bone from Big Bone Lick, which have been ground by the large pachyderms and ruminants which frequented that swamp. Sometimes these nodules do not make up more than a considerable fraction of the bed, the remainder being sand, pebbles, or the marl of the character found on the bed beneath. Again, the nodules are so crowded in the bed that they are soldered together into one mass, with scarce any interspaces between the separate concretions.

Mingled with the concretions there is found a very variable quantity of fossil vertebrate remains; by far the greater part of these consist of exceedingly worn fragments of cetacean bones and sharks' teeth and vertebræ, both clearly of the same species as those found lower down in the marls in the same section. Mingled with these, but comparatively rarely found, are the bones of the fossil horse, pig, mastodon, and bones and utensils of man. The last-named fossils are almost always in a state of preservation, widely different from that of the remains of the cetaceans and selachians with which they are mingled. Their appearance indicates a comparatively recent inhumation.

Chemical analysis shows us that the nodules of this deposit contain the greatest quantity of phosphate of lime, the quantity varying at different points from 40 to nearly 70 per cent. The first and most natural seeming explanation of the large amount of this salt is, that it is derived from the bones and excrements of the animals whose remains are found in the bed. But the points where the most bones are found are not those where the phosphate deposit is thickest or richest. At Chisholm's Island, on the waters of St. Helena Sound, where the bed has the greatest development yet discovered, and where the analysis shows more phosphoric acid than at some of the localities of the richest in bones, the remains of vertebrate animals are very rarely found. It is not too much to say that at this locality not one part in ten thousand of the mass is composed of vertebrate remains. Nor can we assume that the mass of phosphoric acid has been furnished by the decay of bones which have been utterly broken down; in that case we should have the remaining bones showing all degrees of preservation. This, however, is not the case; the fragments, though usually much worn, retain their structure very well. Although I went upon the ground with a disposition to regard the beds as the results of the decay of vertebrate remains, the general character of the deposit soon compelled me to seek some other explanation of its origin.

It has been suggested by a distinguished chemist that the deposit was the result of the submergence of a great guano area, during which submergence the bones of marine animals became mingled with the mass. There are several objections to this view: in the first place, no remains of birds have been found in the deposit, though fossils quite as likely to be destroyed are well preserved there. Then it is difficult to see how in the immediate past this swampy shore could have been the breeding place of the quantities of birds which would have been required to have accumulated these phosphates, nor could we suppose that the climate of this shore could have been at the time of the deposition of the phosphates so different from what it is at present as would have been required to produce the dry conditions essential to the accumulation of a guano deposit.

There is another view of the origin of these phosphate beds, which, so far as my knowledge goes, has not yet been suggested, and which, it seems to me, solves a part of the difficulties.

The phosphate layer rests upon a mass of marl containing a number of fossils which are found in a worn condition mingled with the phosphate nodules. The analyses of Dr. St. Julien Ravenel have shown that at several points beneath the phosphate beds the marl contains several per cent. of phosphate of lime, and it may be assumed as eminently probable that the whole of the marl beneath the region where the phosphate beds occur contains a certain quantity of this material, mingled with the carbonate of lime which constitutes the mass. Now it is a well-known fact that water containing carbonic acid gas in solution has a solvent action upon both these salts of lime, but that its power is greatest on the carbonate of lime. So that a mass of marl containing both these materials, submitted to the action of water charged with carbonic acid, might have the carbonate of lime entirely removed, and the mass left behind when the solving action ceased might consist almost altogether of the phosphate of lime.

If we look a moment at the conditions which prevail in the phosphate region, we shall see that with this view we can easily frame an explanation of the formation of this phosphate layer. The usual section through these beds gives us on top a layer of vegetable matter and soil containing humus, through which the water percolating becomes charged with carbonic acid; then the phosphate layer; immediately beneath that the marl containing phosphates, which is only slightly permeable to water. Soaking over this marl the water becomes charged with carbonate of lime and some phosphate which it carries away in the drainage system of the country. This process, going on for centuries, gradually dissolves away a great thickness of the marl, and gives, as in the capping bed, an accumulation made up of fossils from the wasted beds, which resisted decay, and could not be washed away; of phosphates which became aggregated into nodules; of remains of man and recent animals, which, falling in the swamp, sank through the soft bog and became trampled in among the nodules by the living animals which inhabited this low land.

Great freshets might lay down several feet of clay and sand, or some re-arranged marl on top of the phosphate layer, thus confusing the record, by making the remains of man and extinct animals associated with his early history in this region seem a part of the ancient marl beds.

Looking upon the phosphate layer as the debris of a large amount of eroded marl, it is no longer a difficult matter to account for the association of fossils found there, which would be inexplicable without some theory of this kind.

Although this view of the derivation of the phosphate beds capping the Ashley River marls seems to clear away a part of the doubt which hides their origin, it discloses another question which is about as difficult to settle. If we are to derive the phosphates from the marl, in what manner are we to account for the presence of this material in the latter beds? I cannot say that

I feel any great satisfaction in the explanation which I am about to offer, which after all is only half an explanation; but inasmuch as it promises to cast some light on what is a rather dark subject, I venture to present it.

It may be premised that the whole question of the formation of phosphates is one of the little understood provinces of geological inquiry. The usual supposition of the vertebrate origin of these accumulations does not fit some of the most conspicuous examples, and the ingenious hypothesis of the able chemist and geologist, Mr. T. Sterry Hunt, which accounts for the origin of the massive apatite beds of the early palæozoic by the action of quantities of unarticulated Brachiopods, separating phosphate of lime from the water of the sea, though doubtless a true cause, is not competent to explain many cases of the occurrence of materials containing phosphoric acid in some of its combinations.

The tolerably uniform dissemination of the phosphate of lime through the marl beneath the phosphates cannot be explained on any theory of the formation of such deposits that has come under my observation. The general character of the marl underlying the phosphates is quite different from what would be supposed from the fact that it contains numerous vertebrate remains. It does not seem to have been a deposit formed near the shore, but rather to have been the product of those agents of deposition which work in the deeper parts of the sea. It was my good fortune to see some of the material brought up from the floor of the Gulf Stream, between Florida and Cuba, from a depth of nearly two hundred fathoms; the resemblance of the general character of this material to the marls beneath the phosphate bed is quite striking. It is by no means improbable that at the time when these beds beneath the phosphate bed were being accumulated, the Gulf Stream flowed over them. The peninsula of Florida did not then exist, and the natural path of the stream must have been just over the region of the Ashley River beds.

The material brought up by the Coast Survey dredging work under the direction of Count Pourtalès, consisting, as has just been stated, of a marly substance, resembling in a general way the marls of the Ashley and Cooper Rivers, has recently been subjected to analysis, and, strange to relate, it, too, contains a considerable amount of phosphoric acid. The analyses are not yet complete, but will in due time be made public by the officer having these dredgings in charge; but enough is known to make it sure that the chemical character of the material now accumulating on the bottom of the Gulf Stream, is likely to show a surprising likeness to that which was laid down on the sea floor where the Ashley and Cooper Rivers beds were formed.

It is not the least singular part of the likeness of the materials on the Gulf Stream floor to the beds beneath the phosphates, that there, too, vertebrate remains abound. The dredge of Count Pourtalès brought up from the bottom of the stream a considerable number of fragments of the bones of the dugong, or some allied animal. It might at first sight seem as if the occurrence of these bones afforded a sufficient explanation of the presence of phosphoric acid in the material composing the floor of the Gulf Stream, but here, as on the Ashley and Cooper Rivers marls, it would be necessary to suppose that a large part of the sediment falling on that floor (probably at least one-third of the mass) was the product of vertebrate animals. This is clearly by no means a probable supposition.

We know that some of the pteropod mollusks, forms which are frequently abundant in the ocean at great distances from the land, have a composition not materially different from that of bones. It has even been stated, though I do not yet know by what authority, that some of the marine algæ contain a large per cent. of phosphate of lime. The fact of the existence of this material in a number of the inferior organizations of the sea makes it, in most cases, more reasonable to account for the formation of extensive masses of phosphate beds by the deposition of the remains of invertebrate species, than to suppose that they were accumulated by vertebrate animals.

If the foregoing view of the process by which the phosphate beds of South Carolina were formed be correct, then we may draw the important conclusion, important at least in an economic point of view, that wherever the phosphate-containing marls of the South Atlantic sea-board lie in a position similar to that which they occupy in the vicinity of Charleston, the bed of nodular phosphate is likely to be found. The United States Coast Survey is about undertaking a careful examination of the region where it is likely that these beds may be found. So that this important source of wealth, not only to the States where it occurs, but to the whole country, may not want for that aid in its development which it may reasonably be expected the Government should give.

There can be no doubt that the area of the nodular phosphates is much underestimated, though how great a part of the region where they occur contains the material in workable quantities, may remain a questionable matter.

It seems likely that the peculiar advantages of these beds will enable them for a long time to control the market for phosphates, at least in this country. They are over great areas, scarcely covered by the soil, so that the labor of excavating is small. The beds are, in most cases, remarkably accessible, on account of the peculiar system of lagoons which intersect the coast. Furthermore, the supply lies in a region which, more than any other in the world, is likely to require a large amount of fertilizing material of this character, to balance the waste brought about by the exportation of raw agricultural products.

The plan for the investigation of the geology of the phosphate region, submitted with this report, embraces complete directions for the preservation of specimens, and for recording evidences of the results obtained.

NOTE.—It is a pleasure to me to acknowledge my obligation to Dr. St. Julien Ravenel for the great assistance kindly rendered by him during my examination of the South Carolina beds; he, having been the first to see the commercial value of these beds and a constant student of their features since their discovery, is now the person best acquainted with their phenomena. I account it a very fortunate thing that I had his guidance over a considerable part of the region I traversed.

# APPENDIX No. 20.

ON THE MOON'S MASS AS DEDUCED FROM A DISCUSSION OF THE TIDES OF BOSTON HARBOR, BY WILLIAM FERREL, ESQ.

CAMBRIDGE, MASSACHUSETTS, *June* 24, 1871.

DEAR SIR: I have the honor to submit the following additional report of the discussion of the tide-observations made at the Boston dry-dock. The object of this part of the discussion is to try whether the principles and method used by Laplace in determining the moon's mass and other constants from the tide-observations of Brest will give satisfactory results when applied to the Boston tides; and, if not, to see whether his conditions, when modified by the necessary effect of friction depending upon a higher power than the first power of the velocity, if there is any such sensible effect, will give better results, and furnish a corroboration of the results which have been already obtained in a different manner, and given in the previous report.

1. Laplace, in his last tidal researches, given in the fifth volume of the "Mécanique céleste," gave six conditions for determining the moon's mass and other constants, and for the verification of theory, based upon the relations between the theoretical expressions corresponding to the mean lunar and solar disturbing forces when in conjunction and in opposition near the time of the equinoxes and the solstices, and to the lunar disturbing forces near perigee and apogee, and the observed tidal co-efficients corresponding to these forces under these six different circumstances. If these conditions be made to refer to the exact time of the equinoxes and solstices, and to the mean maximum and minimum of the lunar parallactic inequality, they can be substantially expressed in the following form:

$$(1) \qquad \begin{cases} A = e\,(1 - 0.426\,E) + 0.0249 + 0.0089\,E \\ B = 0.1638 + 0.0500\,E \\ C = 0.0860\,(1 + e)\,(1 - 0.460\,E) + 0.0006\,E \end{cases}$$

in which—

$A$ = the difference between the mean tidal co-efficient of the equinoctial and solsticial syzigies and the mean lunar tidal co-efficient, divided by the latter;

$B$ = the co-efficient of the tide depending upon the principal term in the lunar parallactic inequality divided by the mean lunar tidal co-efficient;

$C$ = the difference between the mean tidal co-efficient of the equinoxes at syzigy and at quadrature, and the mean lunar tidal co-efficient, divided by the latter;

$e$ = the ratio of the mean solar to the mean lunar disturbing force; and

$E$ = one-half of Laplace's $x$, a constant depending upon the change in the tidal co-efficient corresponding to any change in the rate of motion of the disturbing body in right ascension.

The significations of $e$ and $E$ here are the same as in the expressions of the previous report.

In the right-hand member of the first equation, $e\,(1 - 0.426\,E)$ is the expression of the co-efficient of the mean solar tide in terms of the co-efficient of the mean lunar tide. The other two terms of this member express the tidal co-efficient belonging to the term in the lunar parallactic inequality depending upon the argument of variation, which is the same as that of the lunar phase and semi-monthly inequality. The numerical co-efficient 0.426 is equal to twice Laplace's $(m - m')$, expressed in terms of the radius. The right-hand member of the second equation is the expression of the tidal co-efficient belonging to the principal terms in the lunar parallactic inequality. The right-hand member of the last equation is the expression of the co-efficient of the tide corresponding to the sum of the declination-inequalities in the forces of the moon and sun. The term 0.0006 E in this expression is a very small effect, corresponding to an irregularity of the moon's motion in right ascension, depending upon the node. This small term was not taken into account by Laplace, and its effect was insensible in the conditions formed from the tides of Brest; but it should not be neglected in the case of the tides at Boston, where its effect is much greater on account of the large value of E at that port.

The literal expressions of the preceding conditions can be deduced from those of Laplace, except the small term 0.0006 E, and the substantial identity of the two forms of the conditions has been verified by obtaining the same numerical results from both forms. We shall, therefore, regard them as the same as Laplace's conditions, and, on account of their conciseness and convenience, we shall use them in this form in preference to the form in which Laplace has given them.

With the values of A, B, and C obtained from observation, either two of the preceding equations are sufficient for determining the unknown quantities $e$ and E; and if the conditions are correct, these results can then be verified by substitution in the third. When $e$ is known, the moon's mass, $\mu$, is obtained from the equations given in the previous report.

$$(2) \qquad \begin{cases} \mu = 0.0130 + \delta\mu \\ e = 0.4380 - 33.8\,\delta\mu \end{cases}$$

2. In order to obtain the values of A and C in the preceding conditions, it is necessary to have the co-efficient of the mean tides of the equinoctial syzigies, the equinoctial quadratures, the solstitial syzigies, and the solstitial quadratures. In order to determine these, Laplace used, in the case of the syzigies, the excess of the high water of the evening over the low water of the morning, relative to the day which preceded the syzigies, to the day of the syzigies, and to the four days following the syzigy, and used in this way the three syzigies of each year which are nearest to each one of the equinoxes or solstices, doubling the results of the middle syzigy in each case, in order to eliminate the effects of the variation of the moon's parallax. In the quadratures he used the excess of the high water of the morning over the low water of the evening relative to the day of the quadrature and to the three days which follow it for each of the equinoxes and solstices, just as in the case of the syzigies. He used a shorter range of observations in the quadratures, because the change there is much more rapid than in the syzigies. It is proposed in this discussion to carry out this plan in substantially, if not precisely, the same manner. And on account of the completeness of the set of observations of the Boston dry-dock, this plan of Laplace's can be carried out more completely in the case of the Boston tides than Laplace was able to do it in the case of the tides of Brest; for in the latter the observations at the quadratures were generally made only three times and often only twice a day, so that Laplace could use only one high and one low water of each day, whereas in the case of the Boston tides, in which the observations were made without intermission both day and night, two sets of high and low waters could be used for each day, and the observations were made with so great regularity that only two observations of all the groups used were wanting.

3. The following tables contain for each year the sums of the differences between high water and the following low water for each of six consecutive lunar days belonging to the three syzigies or quadratures nearest to the equinoxes and solstices, doubling the results of the middle one for the reason stated above. Hence, with the middle one doubled, there are eight differences for each equinox or solstice, and consequently the sums in the tables result from 16 observations. Hence the averages at the bottom divided by 32 give the tidal co-efficients, or half-ranges, of the tide, denoted by $f_0, f_1$, &c.

TABLE I.—*Equinoctial syzigies.*

| Year. | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| 1848 | 175.27 | 184.84 | 186.35 | 185.77 | 177.19 | 168.84 |
| 1849 | 172.10 | 177.94 | 184.95 | 184.88 | 182.51 | 176.22 |
| 1850 | 169.71 | 180.71 | 184.53 | 182.21 | 185.25 | 171.90 |
| 1851 | 171.00 | 181.01 | 181.04 | 184.45 | 183.58 | 176.33 |
| 1852 | 168.00 | 176.03 | 187.62 | 187.34 | 186.48 | 177.95 |
| 1853 | 168.12 | 178.79 | 184.63 | 181.30 | 182.65 | 173.19 |
| 1854 | 162.03 | 172.42 | 181.10 | 184.17 | 180.85 | 174.47 |
| 1855 | 168.33 | 180.00 | 187.86 | 189.40 | 181.17 | 169.97 |
| 1856 | 163.68 | 172.99 | 182.31 | 188.20 | 181.26 | 171.18 |
| 1857 | 164.31 | 174.60 | 179.33 | 180.16 | 177.28 | 167.31 |
| 1858 | 170.52 | 177.85 | 180.57 | 179.18 | 174.64 | 164.28 |
| 1859 | 171.62 | 179.08 | 184.96 | 183.16 | 171.74 | 162.76 |
| 1860 | 173.92 | 182.92 | 186.05 | 182.02 | 173.56 | 159.90 |
| 1861 | 173.64 | 183.85 | 188.56 | 183.96 | 175.98 | 165.36 |
| 1862 | 172.84 | 179.94 | 183.82 | 183.84 | 176.70 | 168.78 |
| 1863 | 175.08 | 180.34 | 182.84 | 180.84 | 174.16 | 165.32 |
| 1864 | 166.70 | 172.40 | 179.74 | 176.22 | 173.90 | 165.30 |
| 1865 | 171.00 | 182.84 | 185.84 | 184.52 | 182.62 | 171.64 |
| 1866 | 166.69 | 175.18 | 180.97 | 182.09 | 181.15 | 171.72 |
| Means | 169.68 | 178.62 | 183.84 | 183.35 | 179.09 | 169.60 |
| Tidal co-efficients. | 5.3025 $=f_0$ | 5.5814 $=f_1$ | 5.7450 $=f_2$ | 5.7297 $=f_3$ | 5.5945 $=f_4$ | 5.3000 $=f_5$ |

TABLE II.—*Equinoctial quadratures.*

| Year. | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| 1848 | 150.15 | 139.17 | 136.62 | 134.79 | 144.10 | 151.19 |
| 1849 | 151.26 | 143.93 | 140.94 | 136.35 | 144.56 | 151.11 |
| 1850 | 150.56 | 144.08 | 137.12 | 137.33 | 143.37 | 151.47 |
| 1851 | 150.40 | 146.02 | 139.54 | 136.27 | 138.94 | 146.53 |
| 1852 | 155.65 | 143.70 | 135.51 | 132.77 | 134.22 | 147.13 |
| 1853 | 145.85 | 134.82 | 129.27 | 126.50 | 130.48 | 144.67 |
| 1854 | 147.70 | 140.81 | 129.17 | 124.28 | 129.62 | 138.52 |
| 1855 | 146.01 | 134.47 | 125.21 | 125.48 | 129.95 | 139.30 |
| 1856 | 149.81 | 138.49 | 124.12 | 124.82 | 129.07 | 141.22 |
| 1857 | 144.87 | 137.89 | 125.70 | 123.78 | 124.20 | 142.99 |
| 1858 | 141.36 | 132.18 | 121.89 | 130.97 | 128.17 | 145.02 |
| 1859 | 143.90 | 134.13 | 126.32 | 128.40 | 136.18 | 148.76 |
| 1860 | 144.68 | 132.76 | 131.64 | 132.76 | 142.30 | 156.07 |
| 1861 | 143.28 | 131.86 | 128.96 | 130.10 | 136.66 | 147.02 |
| 1862 | 144.36 | 134.96 | 132.50 | 131.14 | 138.36 | 147.26 |
| 1863 | 143.26 | 136.82 | 132.24 | 130.15 | 137.18 | 149.50 |
| 1864 | 148.02 | 135.72 | 130.46 | 133.06 | 139.14 | 148.40 |
| 1865 | 148.80 | 139.92 | 133.32 | 137.46 | 145.52 | 156.76 |
| 1866 | 153.83 | 142.08 | 134.61 | 131.30 | 136.18 | 147.37 |
| Means | 148.19 | 138.10 | 131.32 | 130.93 | 136.22 | 147.38 |
| Tidal co-efficients. | 4.6310 $=f_0$ | 4.3155 $=f_1$ | 4.1037 $=f_2$ | 4.0915 $=f_3$ | 4.2570 $=f_4$ | 4.6050 $=f_5$ |

TABLE III.—*Solstitial syzigies.*

| Year. | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| 1848 | 172. 01 | 179. 81 | 180. 52 | 177. 39 | 166. 78 | 166. 76 |
| 1849 | 170. 95 | 179. 49 | 183. 87 | 185. 31 | 174. 20 | 169. 99 |
| 1850 | 169. 91 | 173. 16 | 186. 98 | 187. 38 | 180. 19 | 168. 84 |
| 1851 | 165. 35 | 172. 57 | 177. 30 | 175. 43 | 170. 96 | 166. 75 |
| 1852 | 168. 70 | 181. 31 | 184. 64 | 180. 09 | 169. 91 | 158. 76 |
| 1853 | 170. 62 | 171. 90 | 178. 45 | 182. 24 | 177. 65 | 161. 58 |
| 1854 | 164. 03 | 174. 11 | 175. 14 | 172. 35 | 162. 68 | 160. 78 |
| 1855 | 165. 41 | 175. 69 | 180. 64 | 177. 01 | 168. 08 | 161. 97 |
| 1856 | 167. 02 | 176. 64 | 180. 55 | 180. 82 | 178. 17 | 164. 79 |
| 1857 | 162. 48 | 165. 68 | 165. 67 | 166. 82 | 163. 00 | 160. 56 |
| 1858 | 163. 51 | 170. 52 | 168. 11 | 176. 68 | 169. 93 | 162. 94 |
| 1859 | 160. 79 | 166. 88 | 167. 80 | 170. 44 | 174. 82 | 164. 37 |
| 1860 | 165. 94 | 172. 70 | 172. 74 | 170. 47 | 167. 84 | 165. 30 |
| 1861 | 164. 12 | 169. 66 | 175. 21 | 174. 88 | 173. 02 | 166. 66 |
| 1862 | 164. 94 | 171. 36 | 172. 56 | 178. 40 | 174. 50 | 165. 82 |
| 1863 | 167. 47 | 167. 20 | 172. 74 | 172. 40 | 170. 44 | 166. 44 |
| 1864 | 166. 58 | 178. 34 | 182. 90 | 178. 64 | 171. 56 | 167. 60 |
| 1865 | 173. 24 | 176. 86 | 178. 30 | 180. 08 | 172. 68 | 170. 42 |
| 1866 | 174. 64 | 179. 08 | 180. 79 | 179. 99 | 179. 55 | 168. 90 |
| Means | 167. 20 | 173. 84 | 177. 10 | 177. 22 | 171. 89 | 165. 23 |
| Tidal co-efficients. | 5. 2250 $=f_0$ | 5. 4325 $=f_1$ | 5. 5342 $=f_2$ | 5. 5380 $=f_3$ | 5. 3715 $=f_4$ | 5. 1635 $=f_5$ |

TABLE IV.—*Solstitial quadratures.*

| Year. | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| 1848 | 153. 81 | 148. 25 | 142. 60 | 141. 60 | 147. 32 | 155. 38 |
| 1849 | 153. 30 | 146. 69 | 136. 24 | 142. 76 | 148. 97 | 151. 08 |
| 1850 | 152. 61 | 144. 96 | 142. 79 | 145. 23 | 148. 43 | 155. 29 |
| 1851 | 148. 70 | 145. 21 | 140. 99 | 140. 63 | 143. 65 | 150. 71 |
| 1852 | 141. 75 | 140. 58 | 136. 67 | 139. 24 | 141. 47 | 152. 53 |
| 1853 | 143. 70 | 143. 13 | 140. 98 | 138. 47 | 145. 14 | 151. 69 |
| 1854 | 149. 72 | 143. 59 | 137. 80 | 139. 28 | 144. 03 | 152. 18 |
| 1855 | 144. 39 | 140. 64 | 137. 41 | 142. 44 | 140. 70 | 144. 75 |
| 1856 | 144. 41 | 138. 34 | 132. 30 | 138. 35 | 140. 57 | 146. 31 |
| 1857 | 149. 10 | 145. 09 | 138. 97 | 147. 07 | 152. 85 | 152. 84 |
| 1858 | 148. 14 | 143. 64 | 141. 18 | 139. 24 | 145. 75 | 149. 51 |
| 1859 | 149. 68 | 145. 22 | 138. 10 | 135. 32 | 144. 10 | 151. 30 |
| 1860 | 145. 97 | 140. 92 | 142. 08 | 136. 50 | 139. 18 | 145. 82 |
| 1861 | 149. 66 | 139. 20 | 140. 52 | 142. 10 | 145. 63 | 149. 24 |
| 1862 | 151. 60 | 144. 16 | 138. 28 | 143. 10 | 146. 92 | 153. 98 |
| 1863 | 149. 84 | 141. 54 | 139. 02 | 140. 54 | 146. 40 | 149. 80 |
| 1864 | 148. 66 | 146. 44 | 144. 82 | 142. 24 | 144. 40 | 154. 36 |
| 1865 | 154. 66 | 147. 27 | 141. 88 | 147. 92 | 150. 28 | 154. 34 |
| 1866 | 154. 54 | 145. 65 | 141. 35 | 141. 08 | 149. 48 | 155. 69 |
| Means | 149. 17 | 143. 55 | 140. 21 | 141. 22 | 145. 70 | 151. 57 |
| Tidal co-efficients. | 4. 6615 $=f_0$ | 4. 4860 $=f_1$ | 4. 3815 $=f_2$ | 4. 4130 $=f_3$ | 4. 5530 $=f_4$ | 4. 7365 $=f_5$ |

The groups of the six consecutive lunar days near the time of the syzigies and quadratures, denoted in the preceding tables by 0, 1, &c., were so taken as to throw the maximum of the tide belonging to the syzigies or the minimum belonging to the quadratures as near the middle of the group as possible. Accordingly, the lunar day was made to commence sometimes with the upper and sometimes with the lower transit, so that the maximum or minimum was thus frequently made to fall much nearer the middle than it would otherwise have done. The sums of the differences between high water and the following low water contained in the columns headed 0 are those which immediately follow the seventh transit preceding the syzigy or the quadrature in the Coast Survey records, the transit there used being transit C of Lubbock's notation. Hence, the transit belonging to $f_0$, deduced from a great number of observations, precedes the syzigy or the quadrature by $3\frac{1}{4}$ lunar days. But as the value of $f_0$ belongs to the time which is the mean between high water and the following low water, it belongs to a time which precedes the syzigy or quadrature by $3\frac{1}{8}$ lunar days, minus the lunitidal interval of high water.

4. If with Laplace we assume that $f$ is a function which satisfies with sufficient accuracy the following condition—

$$f = \zeta t^2 + \zeta' t + \zeta'' \tag{3}$$

$t$ being the time reckoned from the epoch of $f_0$, we may, with the six given values of $f$ in the preceding tables, determine, by the method of least squares, the most probable values of the constants $\zeta$, $\zeta'$, and $\zeta''$, in each case, and then determine the values of $f$ and $t$ belonging to the maximum or minimum. The general expressions of the constants given by the six conditions are:

$$(4)\qquad \left\{\begin{aligned} \zeta &= \frac{10\,(f_0 + f_5 - f_2 - f_3) + 2\,(f_2 + f_3 - f_1 - f_4)}{112} \\ \zeta' &= \frac{5\,(f_5 - f_0) + 3\,(f_4 - f_1) + (f_3 - f_2) - 5\zeta}{35} \\ \zeta'' &= \frac{f_0 + f_1 + f_2 + f_3 + f_4 + f_5}{6} - \frac{5}{2}\zeta' - \frac{55}{6}\zeta \end{aligned}\right.$$

If we put—

F = the value of $f$ when a maximum or minimum; and

T = the value of $t$ when $f$ is a maximum or minimum,

we may obtain from the preceding expression of $f$ (3),

$$(5)\qquad \left\{\begin{aligned} T &= -\frac{\zeta'}{2\zeta} \\ F &= \zeta T^2 + \zeta' T + \zeta'' \end{aligned}\right.$$

If, in accordance with our usual notation, we put $\tau$ for the time the maximum of the tidal coefficient follows the time of the maximum of the disturbing force, we shall have, from what has been stated,

$$\tau = T - (3.125 - B_0) = T - 1.163 \tag{6}$$

in which $B_0$, as used in the previous report, is the mean establishment of the port, which, in lunar time, is 1.962 days.

From the six values of $f$ in Table I, we get, by means of (4),

$$\zeta = -0.07254$$
$$\zeta' = +0.36303$$
$$\zeta'' = +5.29955$$

With these constants the values of $f_0$, $f_1$, &c., in Table I, satisfy (3) with an average residual of 0.0054 feet, and a maximum residual of 0.0096 feet. These constants, then, in (5) give—

$$T = 2.502 \text{ days};$$
$$F = 5.7545 \text{ feet}.$$

From the values of $f$ in Table II we get, in the same manner,

$$\zeta = +0.08624$$
$$\zeta' = -0.44021$$
$$\zeta'' = +4.64402$$

With these constants the values of $f_0$, $f_1$, &c., in Table II, satisfy (3) with an average residual of 0.0106 feet and a maximum one of 0.0255 feet. These constants in (5) give—

$$T = 2.552 \text{ days};$$
$$F = 4.0824 \text{ feet}.$$

From Table III, by the same method, we get—

$$\zeta = -0.05626$$
$$\zeta' = +0.26739$$
$$\zeta'' = +5.22460$$

With these constants the values of $f_0$, $f_1$, &c., in Table III, satisfy (3) with an average residual of 0.0090 feet, and a maximum one of 0.0225 feet. With these constants (5) gives—

$$T = 2.376 \text{ days};$$
$$F = 5.5423 \text{ feet}.$$

We likewise get in the same way, from Table IV,

$$\zeta = +0.04961$$
$$\zeta' = -0.23069$$
$$\zeta'' = +4.66063$$

With these constants (3) is satisfied by the values of $f_0$, $f_1$, &c., in Table IV, with an average residual of 0.0100 feet and a maximum one of 0.0224 feet. With these constants (5) gives—

$$T = 2.325 \text{ days};$$
$$F = 4.3925 \text{ feet}.$$

5. The average of the preceding values of T is 2.439 days, which, in (6), gives $\tau = 1.276$ days, which, in solar time, is 1.32 days. This, for some reason, is much less than 1.60 days, the result obtained by a different method, and given in the previous report. With the number of observations, however, which can be used by this method, this quantity cannot be very accurately determined where the tidal co-efficient of the inequality is so small as in the case of the Boston tides.

By taking the average of the four preceding values of F belonging to the syzigies and the quadratures of the equinoxes and the solstices, we get, for the co-efficient of the mean lunar tide,

$$A_0 = 4.9429 \text{ feet}.$$

If we take half the difference between the average of the two values of F belonging to the syzigies, and that of the two values belonging to the quadratures, we get 0.7055 feet, which is the co-efficient of the solar tide, plus that of the small tide depending upon the small term in the moon's parallax having the argument of variation. We shall, therefore, have, for the first constant in our conditions (1), to be determined directly from observation,

$$A = \frac{0.7055}{4.9429} = 0.1427$$

If we also take half the difference between the average of the two values of F belonging to the equinoctial syzigies and solstitial quadratures, and the average of the two values belonging to the equinoctial quadratures and the solstitial syzigies, we get 0.1306 feet, as an approximate tidal co-efficient belonging to the declination-inequality of the moon and sun combined. This would be the true value of the co-efficient, if all the observations used had been exactly at the time of the equinoxes and solstices. But since the observations of the three syzigies or quadratures which were nearest the equinoxes and solstices were used, a correction must be applied to reduce the average result of the observations, so far as they affect this inequality, to the time of the equinoxes and the solstices, in order to obtain the true co-efficient of the declination-inequality.

Since the average motion of the sun from one syzigy to another is 14°.55, and consequently the argument of the inequality changes 29°.1 in that interval, the results of the extreme syzigies or quadratures are reduced to the times of the middle one by dividing by cos 29°.1. Hence, since the observation of the middle syzigy or quadrature was always doubled, we have—

$$\frac{2 \times 0.1306 \text{ feet}}{1 + \cos 29^\circ.1} = 0.1390 \text{ feet},$$

as the value of the tidal co-efficient for the average value of the argument of the inequality belonging to the middle syzigy or quadrature. But this middle syzigy or quadrature does not fall exactly at the time of the equinox or solstice, but within a range extending from a half-interval from one syzigy or quadrature to another preceding the equinox or solstice to the same time following it, and hence the argument of the inequality varies in this interval 29°.1. In the average of a great many observations we may assume that they are equally distributed through the interval, and hence we shall have—

$$0.1390 \times \frac{14^\circ.55}{\sin 14^\circ.55} = 0.1405 \text{ feet},$$

for the true value of the co-efficient of the declination-inequality. We shall, therefore, have for the value of the constant in the third of our conditions (1), which is to be determined directly from observation,

$$C = \frac{0.1405}{4.9429} = 0.0284$$

Instead of the preceding reductions of the results obtained from observation to make them correspond with the forces at the exact times of the equinoxes and solstices, Laplace used the forces corresponding with the observations by taking the sum of the squares of the declinations belonging to each individual observation used. This was more necessary in his case since he discussed only a partial series of observations to obtain his results, and consequently the effect of the moon's node and other inequalities could not have been so completely eliminated as in the case of the Boston tides, in which a complete series of observations have been used. The amount of both the preceding corrections is only about one-eighth of an inch, so that any possible error arising from the preceding method in obtaining so small a correction must be entirely insensible.

6. It still remains to determine from the observations the constant B in the second of the conditions of (1). In order to do this, we shall avail ourselves of the results which have been already obtained with much labor, and given in Table III of the preceding report, using for the purpose those only falling within a certain range at the perigee and apogee of the moon. By taking one-half the difference between $H_1$ and $H_2$, that is, of high water and the following low water, since the results thus obtained will be from a great number of observations made under all possible circumstances, we obtain the average values of the tidal co-efficient contained in the following table, belonging to the given arguments of transit and moon's mean anomaly:

TABLE V.—*Moon's mean anomaly.*

| ☽'s transit. | 0 | 15 | 30 | 45 | 60 | 75 | 180 | 195 | 210 | 225 | 240 | 255 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *h. m.* | | | | | | | | | | | | | |
| 10 15 | 6.40 | 6.30 | 6.33 | 6.25 | 6.37 | 6.16 | 4.72 | 4.70 | 4.60 | 4.61 | 4.64 | 5.03 | $=f_0$ |
| 10 45 | 6.44 | 6.56 | 6.48 | 6.53 | 6.32 | 6.10 | 4.82 | 4.69 | 4.76 | 4.66 | 4.95 | 4.91 | $=f_1$ |
| 11 15 | 6.42 | 6.57 | 6.65 | 6.58 | 6.36 | 6.13 | 4.82 | 4.78 | 4.82 | 4.73 | 4.72 | 4.99 | $=f_2$ |
| 11 45 | 6.65 | 6.55 | 6.73 | 6.62 | 6.31 | 6.17 | 4.81 | 4.72 | 4.81 | 4.68 | 4.90 | 5.04 | $=f_3$ |
| 0 15 | 6.38 | 6.50 | 6.41 | 6.51 | 6.32 | 6.09 | 4.78 | 4.72 | 4.61 | 4.72 | 4.79 | 4.95 | $=f_4$ |
| 0 45 | 6.27 | 6.42 | 6.54 | 6.45 | 6.33 | 6.11 | 4.75 | 4.60 | 4.68 | 4.61 | 4.66 | 4.74 | $=f_5$ |
| | 6.521 $=f'_0$ | 6.586 $=f'_1$ | 6.642 $=f'_2$ | 6.617 $=f'_3$ | 6.309 $=f'_4$ | 6.144 $=f'_5$ | 4.824 $=f'_0$ | 4.772 $=f'_1$ | 4.801 $=f'_2$ | 4.737 $=f'_3$ | 4.855 $=f'_4$ | 5.016 $=f'_5$ | |
| 4 15 | 4.94 | 5.16 | 5.07 | 5.18 | 5.06 | 4.86 | 3.80 | 3.75 | 3.62 | 3.76 | 3.80 | 3.75 | $=f_0$ |
| 4 45 | 4.75 | 4.90 | 4.99 | 4.91 | 4.86 | 4.75 | 3.68 | 3.64 | 3.70 | 3.55 | 3.61 | 3.78 | $=f_1$ |
| 5 15 | 4.68 | 4.83 | 5.06 | 4.90 | 4.79 | 4.57 | 3.69 | 3.60 | 3.56 | 3.62 | 3.55 | 3.68 | $=f_2$ |
| 5 45 | 4.75 | 4.82 | 4.86 | 4.90 | 4.80 | 4.71 | 3.68 | 3.58 | 3.54 | 3.57 | 3.60 | 3.60 | $=f_3$ |
| 6 15 | 5.00 | 4.86 | 4.99 | 4.88 | 4.83 | 4.76 | 3.60 | 3.62 | 3.54 | 3.53 | 3.61 | 3.66 | $=f_4$ |
| 6 45 | 5.10 | 5.08 | 4.94 | 5.02 | 4.95 | 4.90 | 3.75 | 3.64 | 3.73 | 3.59 | 3.66 | 3.78 | $=f_5$ |
| | 4.714 $=f'_0$ | 4.792 $=f'_1$ | 4.942 $=f'_2$ | 4.886 $=f'_3$ | 4.774 $=f'_4$ | 4.625 $=f'_5$ | 3.674 $=f'_0$ | 3.582 $=f'_1$ | 3.547 $=f'_2$ | 3.544 $=f'_3$ | 3.558 $=f'_4$ | 3.652 $=f'_5$ | |

The values of $f'_0, f'_1, f'_2$, &c., are the maxima in the case of the syzigies and the minima in the case of the quadratures of the functions $f_0, f_1, f_2$, &c., in the columns under which the former are placed, and have been determined by the formulæ (3), (4), as in the preceding cases, $f'_0, f'_1$, &c., in each case corresponding to F in the formulæ.

If we now determine by the same formulæ the maximum or minimum, F, of each of the series of values $f'_0, f'_1, f'_2$, &c., varying with the argument of mean anomaly, we get the mean tidal co-efficient belonging to the syzigies of perigee and apogee and to the quadratures of both perigee and apogee.

From the first of the above series belonging to the syzigies of the perigee we get—

$$T = 1.671$$
$$F = 6.6389 \text{ feet.}$$

From the second belonging to the syzigies at apogee we get—

$$T = 1.856$$
$$F = 4.7496$$

From the third belonging to the quadratures of perigee we get—

$$T = 2.296$$
$$F = 4.9043 \text{ feet.}$$

From the fourth belonging to the quadratures of apogee we get—

$$T = 2.715$$
$$F = 3.5322 \text{ feet.}$$

The unit in time of the preceding values of T is the mean time in which the moon's mean anomaly changes 15°, which is 1.143 days.

The average of the preceding values of T is 2.134, which, being multiplied by 1.143 days, gives 2.439 solar days. From this we must subtract one-eighth of a lunar day, or 0.129 day, it being one-half the interval from high to low water, and also the lunitidal interval, and add two days, since the arguments of mean anomaly were taken for a time two days after transit to which the lunitidal interval refers, for reasons stated in the previous report. These reductions being made, we get 2.281 days for the time the maximum of this inequality follows the time of the maximum of the disturbing force. This value differs but little from 2.24 days obtained by a different method, and given in the previous report.

7. If we take one-half the difference between the mean of the two preceding values of F belonging to the perigee, and the mean of the two belonging to apogee, we get 0.8153 feet for the tidal co-efficient of the mean parallactic inequality. Hence, we get for the constant, to be obtained from observation, in the second of the equations (1),

$$B = \frac{0.8153}{4.9429} = 0.1650$$

With the preceding values of A, B, and C, obtained from observation, our conditions (1) become—

$$(7) \qquad \begin{cases} 0.1178 = e\,(1 - 0.426\text{ E}) + 0.0089\text{ E} \\ 0.0012 = 0.0500\text{ E} \\ 0.0284 = 0.0860\,(1 + e)\,(1 - 460\text{ E}) + 0.0006\text{ E} \end{cases}$$

8. Laplace, in the case of the tides of Brest, solved the first and third, (1), or their equivalents, with A and C determined from observation, and thus obtained the two unknown quantities corresponding to our $e$ and E, and from the former of these two he determined the moon's mass to be very nearly $\frac{1}{75}$ of that of the earth. But the results which he thus obtained, substituted in the second equation, gave the value of B, the tidal co-efficient of the parallactic inequality, about one-tenth part, or 1.5 inches, too large for observation; so that, although his mass of the moon is perhaps not much in error, his results obtained from the first and third conditions did not satisfy the second, and he admitted that the discrepancy did not fall within the limits of the errors of observation.

If we now take the same two conditions in the case of the Boston tides, they become, with the values of A and C, which have been determined from observation, the first and third of (7). The solution of these two equations gives—

$$e = 0.3480$$
$$E = 1.655$$

With this value of $e$ we get from (2), for the moon's mass,

$$\mu = \frac{1}{64}$$

If we now, by way of verification, substitute the preceding value of E in the second of (1), we get a value of B about one-half, or nearly five inches, too large for that obtained from observation. It is seen, then, that, in the case of the Boston tides, Laplace's conditions, or their equivalents, cannot be even approximately satisfied by observation, and the moon's mass obtained from them by a method which is substantially the same as Laplace's is evidently much too large.

It will, no doubt, be found that the tendency of Laplace's conditions is to give in all parts a mass of the moon too large, and that the error is somewhat in proportion to the deviation of the conditions from those of the equilibrium-theory, that is, to the value of E. Hence, while in the case of the Boston tides, where the value of E is very large, they give a mass of the moon much too large at Brest, where the value of E is only about one-fourth as much, the mass of the moon obtained from them is perhaps not much too great.

The mass of the moon which Laplace would have obtained from the first and second of his conditions, as they are given in (1), would have been much too large, and the mass which Airy obtained from substantially the same conditions, deduced from the tides of Ireland, was nearly double the probably true value. It is readily seen from mere inspection that, in the case of the Boston tides, the same conditions, the first and second of (7), would give a mass about four times the true mass.

9. It is seen, then, that the conditions deduced from Laplace's theory do not give, in general, a satisfactory mass of the moon, and that no mass can be obtained which will make the theory represent observation. Let us, therefore, try now whether more satisfactory results can be obtained from the theory as modified by the effect of friction increasing in a greater ratio than the first power of the velocity. The introduction of such a term into the primary tidal conditions destroys their lineal character, and the effect of such a term upon the tidal co-efficient deduced from the conditions is greater in large than in small tides; and when the expression of this co-efficient is developed into terms consisting of the constant or principal term and the inequalities, friction is found to affect the inequalities in a different ratio from that of the principal term, and consequently affects the ratios of the inequalities to the constant term. Hence, the conditions in the case of no-friction, or of friction increasing with the first power of the velocity, become, in the case in which it is supposed to increase in a greater ratio than the first power, of the following form, in which F denotes the effect of friction:

$$\text{(8)} \qquad \begin{aligned} (1+F)\,A &= e(1-0.426\,E) + 0.0249 + 0.0089\,E \\ (1+F)\,B &= 0.1638 + 0.0500\,E \\ (1+F)\,C &= 0.0860\,(1+e)\,(1-0.460\,E) + 0.0006\,E \end{aligned}$$

The right-hand members of these conditions differ by quantities of a second order from those of the conditions given in the previous report, depending upon different developments, while there is a corresponding difference in the quantities in the left-hand members, which have to be obtained from observation by very different methods in the two cases. Hence, the latter conditions furnish a very good check upon the former, both so far as theoretical errors are concerned and also unavoidable inaccuracies in obtaining the quantities in the left-hand members from a discussion of the observations.

The solution of the preceding equations, using for A, B, and C the values which have been obtained from observation, gives—

$$e = 0.4275$$
$$E = 1.464$$
$$F = 0.484$$

With this value of $e$ (2) gives, for the moon's mass,

$$\mu = \frac{1}{75.1}$$

This result, which is very nearly that obtained by Laplace from the observations at Brest, differs considerably from $\frac{1}{78.6}$ obtained from the conditions of the previous report; but the probable error of any single determination from conditions obtained from the Boston tides is considerable on account of the unfavorableness of the conditions, as explained in that report. The mean of these two results is perhaps not much in error.

10. The preceding large value of F shows that there is a term of that sort needed in theory to reconcile it with observation, and the same is indicated by the tides at Brest, though in the latter the value of F is much less than at Boston. That this depends in a great measure, if not entirely, upon friction, I think there can be but little doubt; but in cases in which E is large, as at Boston, it may be due in part to neglected terms in a development in which E is only the term of the first order. Or, stated otherwise, the principle assumed by Laplace, that the change in the tidal co-efficient due to a change of velocity of the disturbing body in right ascension is proportional to the amount of change in this velocity, may not be strictly correct, and there may be in some cases a considerable effect due to terms depending upon the squares of these changes. These effects would all have the same sign, and would be approximately represented by such a term as F above.

11. If we take the mean of the results obtained from both methods, we shall have $\frac{1}{76.7}$ for the moon's mass obtained from the Boston tides. This mass gives 9".34 for the co-efficient of the principal term of lunar nutation, and 6".85 for the co-efficient of the lunar term in the solar tables.

Very respectfully, yours,

WM. FERREL.

Professor BENJAMIN PEIRCE,
*Superintendent United States Coast Survey.*

# APPENDIX No. 21.

ON THE THEORY OF ERRORS OF OBSERVATIONS, BY ASSISTANT C. S. PEIRCE.

The object of this paper is to give a general account of the theory of errors of observations, with the design of showing what the limitations to the applicability of the method of least squares are, and what course is to be pursued when that method fails. We shall begin with an elementary account of the general principles of the subject, in order to state them with a little more accuracy than is commonly done.

The notation employed is one which has been suggested by the study of the logic of relations. Small Roman letters will denote objects partly indeterminate. Thus m may denote a man, without saying what man. Small Italics will be used for relative terms; thus $l$ may denote a lover. The correlates of such relative terms will be written after them on the same line; thus $t$m or $l$m may denote a tooth of a man or a lover of a man, if m denotes man, $t$ a tooth of and $l$ a lover of something undetermined. Then, $l$w will denote a lover of a woman, it being indeterminate what lover and what woman. $t\,l$w will denote a tooth of a lover of a woman. If we wish to denote that which is a lover of all women, we must have a symbol to denote all women. As [x] is commonly used in the method of least squares to denote the sum of all the quantities x, so we may write [w] to denote all women, and then $l$ [w] will denote something which is a lover of all women, or we may write the same thing thus, $l^{\mathrm{w}}$. A relative term has a double indeterminacy, being indeterminate in reference to the relate and also in reference to the correlate. A lover may be this lover, that lover, or the other lover, and each of these may be lover of this, or that, or the other. Corresponding, therefore, to the [$l$], which denotes all lovers, we may write $\left\{ l \right\}$ to denote the lover to whomever he is a lover. Thus, $\left\{ l \right\}^{\mathrm{w}}$ will denote a lover of nothing but women, or we may write the same thing thus, ${}^{l}\mathrm{w}$. We may denote "loved by" by $K'$.

Corresponding to any absolute term, as man, there is a relative term, "man that is," as in the expression "a man that is rich." I shall denote a relative of this sort by the symbol for the absolute term, with an inverted comma after it, as m$_{\text{‘}}$. Thus, if b denotes anything black, m$_{\text{‘}}$ b will denote a man that is black.

Let $V$ be the relative "a general name which is applicable to." Thus, $V$m will denote a general term which is applicable to some man. $V^{\mathrm{m}}$ will denote a general term which is applicable to every man. $V^{\mathrm{m}}{}_{\text{‘}}\ V^{\mathrm{w}}$ will be a general term which is applicable to every man and to every woman. $K\ V\,[V^{\mathrm{m}}{}_{\text{‘}}\ V^{\mathrm{w}}]$ will denote that to which every general term is applicable which is applicable to every man and to every woman; in other words, this denotes either a man or a woman. I shall write this for short m $+\!\!,$ w.

Zero is defined by the general equation $x +\!\!, 0 = x$, whatever $x$ may be. Then, *zero* generally denotes nothing.

Unity is defined by the general equation x$_{\text{‘}}$ 1 = x, whatever x may be, and then 1 generally will denote anything.

But 1 and 0 have sometimes to be interpreted as relative terms. Now, it can be proved by the principles of the logic of relatives that so considered $0^{\mathrm{x}} = 0$, unless x = 0, when $0^0 = 1$; and that 1 x = 1, unless x = 0, when 10 = 0. It follows that $0^{\mathrm{x}}$ is such a logical function* of x that it signifies "the case of the non-existence of," while $1x$ is such a logical function of $x$ that it signifies "the case of the existence of."

* A mathematical function of $x$, such as $\phi x$, is something whose value is obtained by mathematical processes when $x$ is given. A logical function of $x$, of which we have, as common examples, letters with a subscript $x$, as $\mathrm{P}_x$, is something whose signification is logically deducible when the signification of x is known.

## ERRATA IN APPENDIX No. 21.

*Page* 203. $\Xi$ should be subscript in all the formulæ instead of on the line.
*Page* 207. At end of first paragraph, strike out the last sentence.
*Page* 207. Seventh line of last paragraph, for *induced* read *used*.

Since [m] denotes all men, we may naturally write $\frac{[\mathrm{m}]}{\mathrm{m}}$ to denote what all men become when that factor is removed which makes [m] refer to *men* rather than to anything else; that is to say, to denote the *number* of men. We may write this for short $\Big[\mathrm{m}\Big]$ with heavy brackets. Then $t$ being a relative term, ("a tooth of,") by $\Big[\mathrm{t}\,1\Big]$ will be denoted the total number of teeth in the universe. But $\Big[\mathrm{t}\Big]$ will be used as equivalent to $\frac{[\mathrm{t}\,1]}{[1]}$, or the average number of teeth that anything has. But "anything" is not to be taken here in an absolute sense. We always limit our considerations entirely to a certain class. As De Morgan expresses it, we always have a limited universe. When we reckon up the number of all things to find the average number of teeth *per* thing, it would be absurd to count among things the virtues, shades of color, days or seconds of time. Anything which belongs to the limited universe under consideration is called, in the theory of probabilities, an *event*. An expression like $\Big[t\Big]$, where $t$ is a relative term, is termed a relative number, average number, or probable number. If the relative term to which the average number refers is one of those relatives which are formed by adding a comma to the symbol for an absolute term, as m, then the relative number is called a *probability*. For example, $\Big[\mathrm{m},\Big]$ is the average number of men that anything is, but it is usually called the probability that anything is a man.

The importance of average numbers arises from the fact that all our knowledge really consists of nothing but average numbers; for all our knowledge is derived from induction, and its analogue, hypothesis. Now, the scientific conduct of this kind of reasoning is highly complex, because all sorts of precautions have to be attended to, and it has to be accompanied by a great deal of deduction. But the general nature of induction is everywhere the same, and is completely typified in the following example. From a bag of mixed black and white beans I take out a handful, and count the number of black and the number of white beans, and I assume that the black and white are nearly in the same ratio throughout the bag. If I am in error in this conclusion, it is an error which a repetition of the same process must tend to rectify. It is, therefore, a valid inference. But it clearly teaches me nothing in reference to the color of any particular bean. Of that I am as ignorant as before. The case is not in the least altered if I find all the beans of my handful to be black, or all to be white. I can still infer only the approximate general ratio, and it is only this I express when I say the observation makes the probability of any one bean being white or being black very great; for a probability is itself only an average number. At first thought it is hard to admit this; but the difficulty will be in great measure removed if we consider how it is that the knowledge of average numbers becomes useful in particular cases. Suppose we know the relative number of black beans in a certain bag; then, if we draw a large number of beans out of it, we know that the total number of black beans we shall draw will be equal to the number of drawings multiplied by the average number of beans in the bag. Suppose we know the relative numbers of black beans in a large number of bags, containing different proportions; then, if the beans are well mixed up in each, we may only draw a single bean from each, and yet we can predict nearly the total number of black beans which would be drawn by simply taking the sum of the relative numbers. If the black beans had a value while the white ones were worthless, then the total number of black beans which would be drawn would be the important thing to know. But as knowledge derives its practical importance from its influence upon our conduct, let us suppose that at every drawing we have our choice between two bags to draw from; then the man who knew the relative number of black beans in every bag would act in every case as though the bean he would draw from the bag which contained the larger proportion of black ones were known to be black, and as though the bean he would draw from the other were certainly white. Strictly speaking, he would know nothing about the beans that would be drawn in the particular case, but he would have a knowledge which would be so far equivalent to that that it would influence his conduct in the particular case. This is the only knowledge we ever have, a knowledge of what assumption to make in the particular case in order to do the best in the long run. Whenever, then, we have to do with a *value*, the sum-total of which in the long run is the only thing which concerns us, the average amount of it is important to be known; but in all other cases the average numbers are of no consequence.

It is evident that in the example just given it would be a valuable increase of knowledge to know, for instance, what the difference in the relative number of black beans at the top and bottom of a bag was, and any limitation of the "universe" used which should separate a relative number into two different ones would be advantageous.

There are many problems in probabilities, which, being solved, give a relative number composed of two terms, one known and the other unknown. Such an indeterminate result shows that a wider "universe" must be adopted for one of the terms of the relative number.

The fundamental arithmetical formulæ relating to relative numbers are as follows:

We have seen that the relative number of things that are men, or the probability that a thing is a man, is equal to $\frac{[m, 1]}{[1]}$. By "thing" here is meant any object of our limited universe, as, for example, an animal. But we may wish to consider the relative number of animals that are men when our limited universe is a wider class than animal. In this case, *a* denoting an animal, we write this probability $\frac{[m, a]}{[a]}$. Let us suppose that, our universe being "day," we wish to know the probability that if it thunders on any day it will rain on that day. To say that if it thunders it will rain on the same day is the same as to say that every day on which it thunders is a day on which it rains. Then let t be a day on which it thunders and r a day on which it rains, and the probability in question is $\frac{[t, r]}{[t]}$. In general, the probability that if one event happens another will happen is equal to the probability that both will happen, divided by the probability that the first will happen.

Let us now see how to express the probability that a certain quantity will have a certain value. It is clearly implied that the quantity is defined in some other way than by its value. It might be, for instance, the length of time a bird will be on wing. Let x be this quantity, and let n be any definite value. Then $\frac{[x, n]}{[x]}$, or the number of cases in which the time a bird is flying has that value, divided by the whole number of cases of a bird's flying, is the probability that a bird will fly for that length of time. But since time is continuous, the length of time a bird may be up may have an infinite number of different values. Consequently, the probability of any one is *zero*. We, therefore, seek the probability that the time lies between n and $n + \triangle n$; and if $\triangle n$ is infinitesimal, (say d n,) then the probability is proportional to d n. We may, therefore, write this probability thus, $[n_x]\, d\, n$. Here $n_x$ denotes the case of the value of x being about n.

The probability that if one quantity, $x$, has a value lying between $m$ and $m + d\, m$, then another quantity, $y$, has a value lying between $n$ and $n + d\, n$, will, according to what has been said, be equal to the probability that both $x$ and $y$ will have the supposed values, divided by the probability that $x$ will have the supposed value, or will be $\frac{[m_x, n_y]\, d\, m.\, d\, n}{[m_x]\, d\, m}$, or, since the d $m$ disappeared by cancellation, $\frac{[m_x, n_y]}{[m_x]}\, d\, n$.

Given, the probability of A, the probability of B, and the probability that if A happens, B happens. Required, the probability that if B happens, A happens.

The probability of A is [A].

The probability of B is [B].

The probability that if A then B is $\frac{[A, B]}{[A]}$.

The probability that if B then A is $\frac{[A_{\text{r}} B]}{[B]}$.

Then we have—

$$\frac{[A_{\text{r}} B]}{[B]} = \frac{[A_{\text{r}} B]}{[A]} \times [A] \div [B]$$

or the probability, if B happens that A happens, is equal to the probability if A happens that B happens, multiplied by the probability of A and divided by the probability of B.

We now pass to the theory of observations. An observation gives us the value of a certain quantity which is connected with an unknown quantity in such a way as to be partly dependent on the latter value, and partly on accidental circumstances, not capable of being separately taken account of.

These accidental variations are, however, in all cases subject to a statistical law, so that (observations of a certain kind forming the limited universe, X being the unknown quantity, $\Xi$ the quantity observed) the quantity,

$$\frac{[\xi\Xi_{\text{r}}\ x_{\text{X}}]}{[x_{\text{X}}]}\, d\xi$$

or the probability that if the unknown quantity X has a certain value x, then the observed quantity $\Xi$ will have a value between $\xi$ and $\xi + d\xi$, is a certain arithmetical function of the values $\xi$ and x. If we write $\varepsilon$ for $\xi -$ x, or the error of observation, then we may put $\varphi$ for such a function that—

$$\frac{[\xi\Xi_{\text{r}}\, x_{\text{X}}]}{[x_{\text{X}}]} = \varphi\,(\varepsilon, \text{x})$$

The special form of the function $\varphi$ is called the law of the facility of the errors. Except so far as this law is known, an observation can afford us no information whatever. The following conditions are invariably fulfilled by this function. (It must be understood that only *real* quantities are considered.)

1. It has but one value for each set of values of its variables.
2. Its value is always positive and less than unity.
3. It vanishes when $\varepsilon$ is infinite.
4. Its integral relatively to $\varepsilon$ from $- \infty$ to $+ \infty$ is always unity.

Beyond this the form of the function is determined by the peculiarities of the kind of observations.

The probability that if the observed quantity $\Xi$ has the value $\xi$, then the unknown quantity X has the value $x$ is—

$$\frac{[\text{x}_{\text{X}_{\text{r}}}\, \xi\Xi]}{[\xi\Xi]}\, dx$$

The value of this probability is for any particular kind of observations an arithmetical function of $\varepsilon$ and $\xi$, which we may write $\psi\,(\varepsilon, \xi)\, d\varepsilon$.

The probability that the unknown quantity X has the value $x$ without reference to observation is $[x_{\text{X}}]dx$. This is in any case a function of x, which may be written $\Psi x \,.\, dx$.

The probability that the quantity given by observation $\Xi$ has the value $\xi$, without reference to the value of the unknown quantity, is $[\xi\Xi]\, d\xi$. This an arithmetical function of $\xi$, which may be $\Phi\xi \,.\, d\xi$.

If $\Phi\xi$, $\Psi x$, and $\varphi\,(\varepsilon, \text{x})$ are given, then we can obtain $\psi\,(\varepsilon, \xi)$ thus:

$$\psi\,(\varepsilon, \xi) = \frac{\varphi\,(\varepsilon, \text{x})}{\Phi\xi}\, \Psi x$$

Suppose a number of independent observations to be made. Then we shall have a series of functions—

$$\begin{array}{ll} \varphi_1\,(\varepsilon_1\,, \text{x}) & \Phi_1\,\xi_1 \\ \varphi_2\,(\varepsilon_2\,, \text{x}) & \Phi_2\,\xi_2 \\ \varphi_3\,(\varepsilon_3\,, \text{x}) & \Phi_3\,\xi_3 \\ \text{\&c.} & \text{\&c.} \end{array}$$

then the probability that if the quantities observed have the values $\xi_1, \xi_2, \xi_3$, &c., the unknown quantity X has the value $x$ will be—

$$\Psi \mathrm{X} \cdot \frac{\varphi_1(\varepsilon_1, \mathrm{X})}{\Phi_1 \xi_1} \cdot \frac{\varphi_2(\varepsilon_2, \mathrm{X})}{\Phi_2 \xi_2} \cdot \frac{\varphi_3(\varepsilon_3, \mathrm{X})}{\Phi_3 \xi_3} \cdot \&c.$$

or—

$$\Psi \mathrm{X} \cdot \prod_1^n{}_i \frac{\varphi_i(\varepsilon_i, \mathrm{X})}{\Phi_i \xi_i}$$

The probability $\Psi x.\, dx$ antecedent to *all* observations will be simply $dx$, and, therefore, the factor $\Psi x$ may be omitted in the above expression.

It will be perceived that observation never gives us to know a *number* expressing the value of the unknown quantity, but only a *function* expressing the probability of each value. It happens, however, in a very comprehensive case, that this function assumes a form which involves but two constants, so that in this case observation may be said to give us two numbers, a value for the unknown quantity, and the probable error of that value.

Mr. Crofton's method of considering this case seems to me to make it more comprehensible than any other. Suppose that the unknown quantity X has been observed twice, the values given by observation being $\xi_1$ and $\xi_2$. Put $[\xi]$ for $\xi_1 + \xi_2$. What then is the probability that if $x$ is the value of X, the sum of the values given by the two observations will be $[\xi]$. It is clearly—

$$\int_{-\infty}^{+\infty} \varphi_1\Big(\varepsilon_1, x\Big) \cdot \varphi_2\Big([\varepsilon] - \varepsilon_1, x\Big) \cdot d\varepsilon_1$$

Developing $\varphi_2\Big([\varepsilon] - \varepsilon_1, x\Big)$ by powers of $\varepsilon_1$, this integral becomes—

$$\varphi_2\Big([\varepsilon], x\Big) - \varphi_2'\Big([\varepsilon], x\Big) \int_{-\infty}^{+\infty} \varepsilon_1 \varphi_1\Big(\varepsilon_1, x\Big) . d\varepsilon_1$$

$$+ \tfrac{1}{2} \varphi_2''\Big([\varepsilon], x\Big) \int_{-\infty}^{+\infty} \varepsilon_1^2 \varphi_1\Big(\varepsilon_1, x\Big) . d\varepsilon_1$$

$$+ \tfrac{1}{6} \varphi_2'''\Big([\varepsilon], x\Big) \int_{-\infty}^{+\infty} \varepsilon_1^3 \varphi_1\Big(\varepsilon_1, x\Big) . d\varepsilon_1 - \&c.$$

If in place of two we have $n$ observations, the probability that the sum of all will be $[\xi]$ is—

$$\prod_1^{n-1}{}_i \Big(1 - \int_{-\infty}^{+\infty} \varepsilon_i \varphi_i(\varepsilon_i, x) . \mathrm{D}_i + \tfrac{1}{2} \int_{-\infty}^{+\infty} \varepsilon_i^2 \varphi_i\ (\varepsilon_i, x) . \mathrm{D}^2\varepsilon_i - \&c.\Big)\ \varphi\, n\ \Big([\varepsilon], x\Big)$$

Of these co-efficients—

$$\int_{-\infty}^{+\infty} \varepsilon_i \varphi_i\Big(\varepsilon_i, x\Big)$$

is the probable or mean value of the error of the observed quantity—

$$\tfrac{1}{2} \int_{-\infty}^{+\infty} \varepsilon_i^2 \varphi_i\Big(\varepsilon_i, x\Big)$$

is half the probable value of the square of this error, and so on. The probable value of the error is often less than the probable value of its square, owing to positive and negative errors balancing. But the co-efficients which involve the cube and higher powers of the error may often become insignificant. This, for example, will be the case if $n$ is very great; for then, in comparison with the sum of all the errors, the value of any one will be very small. In fact, in this case we may neglect a quantity a certain number of times, say M, larger than what we could neglect before, and may take a unit of measurement M times larger. Then if—

$$\left[\varepsilon\right],\ \left[\varepsilon^2\right],\ \left[\varepsilon^3\right],\ \&c.,$$

be the probable value of the error, the error square, the error cube, &c., on the old scale of measures, their numerical values on the new scale will be—

$$\frac{\left[\varepsilon\right]}{M},\ \frac{\left[\varepsilon^2\right]}{M^2},\ \frac{\left[\varepsilon^3\right]}{M^3},\ \&c.$$

Consequently if M is sufficiently large, the higher co-efficients may be neglected. It also frequently happens that the error of each observation is due to the combined effect of a great number of independent or nearly independent causes, each one of which alone would produce but an insignificant effect. In this case, by the same reasoning the higher co-efficients will disappear.

The manner in which sensation and volition are propagated through the nerves is unknown, but it must be by some very complicated process, because it is very slow compared with the rate of propagation of sound. It is, therefore, probable that there may be variations of the rate of passage, and that the velocity through each small portion of the whole length of the nerve is to some extent independent of the velocity through the other parts. If this is so, the whole time of propagation would be subject to a variation, the probable values of whose cube and higher powers would be insignificant. However this may be, it appears to be a fact that in all carefully-made observations, the error of which is due to the inevitable inaccuracy of the action of the human nerves, the probable values of the cube, &c., of the errors are very small.

Whenever these quantities disappear it can be proved by an analytical process which need not be reproduced here that—

$$\varphi\left(\varepsilon, x\right) = \frac{h}{\sqrt{\eth}} \mathfrak{S}^{-h^2(\varepsilon - E)^2}$$

where h and E are quantities which depend upon x. We thus reach the fundamental formula of the method of least squares.

It is not the object of this paper to explain that method itself. Only it may be remarked that in the deduction of it which is usually given, it is assumed that what we wish to obtain from observations in any case (whether the method of least squares is applicable or not) is the most probable value of the unknown quantity. This is not the case, for there is but an infinitesimal probability in favor of any one value. Suppose that the cause of error in observing the place of a star were a nearly simple oscillation of the image about its mean point. Then the most probable errors would be the extreme ones. But we should much prefer to assume as the value the probable or mean value than the most probable value, which would be removed the furthest possible from that value. The conception of the matter is this. What observation has to teach us is a *function*, $\psi(\varepsilon, \xi)$, not a mere number. But in cases to which the method of least squares is applicable, this function is completely determined by two numbers, which are the value of the unknown quantity derived from the application of that method and the value of its probable error.*

It is assumed in treatises on least squares that $\Phi\xi . d\xi$, or the probability (without regard to the value of the unknown quantity) that the quantity observed will have a value between $\xi$ and $\xi + d\xi$, is equal to $d\xi$. When this is not the case it is only necessary to weight each observation by dividing by $\Phi\xi$.

* The term probable error is here used in its usual but unanalogical sense, and not for the probable value of the error, which is always assumed to be zero in least squares, or else determined by some special research.

If the probability of error does not follow that law which the method of least squares supposes, that is to say, if the probability of the error x in the mean of a large number of observations is not equal to $\frac{h}{\sqrt{\partial}}\,ϭ^{-h^2x^2}$, where h is a constant independent of x, then it must at least be of this form if h be considered to be a function of x. Now, $h^2$ is the weight which has to be assigned to an observation in the application of the method of least squares; and therefore when this method does not apply in its unmodified form, it is only necessary to find what function of x, h must be in order to give the required law of facility of errors, and then proceed according to the method of least squares, after having weighted each observation by $h^2$. Let the equation which represents the facility of error be plotted, the error being taken as abcissæ, and the probability of that error as ordinate; then plot on the same diagram the curve $y = \frac{1}{\sqrt{\partial}}\,ϭ^{-x^2}$. Let us suppose, then, that a certain value of x, y, is A times as great for the actual curve of errors as it is for the normal least-squares curve. Now, if h be increased in the ratio A, the ordinates will be increased in this same ratio, and the abcissæ will be diminished in the inverse ratio so that the area of the curve is preserved. But if the ordinates at any one point are to be increased in the ratio A, then the abcissæ at that point must be contracted in the inverse ratio, so as to preserve the area; so that if we had a function f x such that $D_x\, f\, x = \frac{1}{a}$, then the probability of this function of the error would follow the law $y = \frac{1}{\sqrt{\partial}}\,ϭ^{-(fx)^2}$, and consequently $\frac{1}{(D_x\, fx)^2}$ is the weight which has to be assigned to any such observation in applying the method of least squares. It will be observed that since the weight depends on the value of the error, it will be necessary first to make an approximate solution of the problem in order to get an approximate value of the error from which to determine the weight, so that when the method of least squares is not applicable in its unmodified form, an approximate method must necessarily be resorted to.

Let us now proceed to consider the method of ascertaining the law of facility of error. In any case, if the error is compounded of an infinite number of infinitely small errors, or approximates to being so, then the law of facility of errors is of that general form which the method of least squares prescribes, and nothing remains indeterminate excepting the value of h. Observation has sufficiently shown that in transit-observations the law of error is of this sort. I copy, for example, from Chauvenet's Astronomy the following table, taken from Bessel's "Fundamenta Astronomiæ," showing the errors made by Bradley in observing Sirius and Procyon:

| Between— | No. of errors by the theory. | No. of errors by experience. |
|---|---|---|
| ″ ″ | | |
| 0.0 and 0.1 | 95 | 94 |
| 0.1 and 0.2 | 89 | 88 |
| 0.2 and 0.3 | 78 | 78 |
| 0.3 and 0.4 | 64 | 58 |
| 0.4 and 0.5 | 50 | 51 |
| 0.5 and 0.6 | 36 | 36 |
| 0.6 and 0.7 | 24 | 26 |
| 0.7 and 0.8 | 15 | 14 |
| 0.8 and 0.9 | 9 | 10 |
| 0.9 and 1.0 | 5 | 7 |
| Over 1.0 | 5 | 8 |

Fechner, in his "Elemente der Psychophysik," has, in connection with his psychophysical law, discussed the applicability of the method to cases of sensation generally such as the estimate of the relative weights of two masses, and he finds that if v be the energy of the force which produces the excitation of any nerve, then if log v be considered as the observed quantity, the errors of the observed quantity will follow the law of least squares. Strictly speaking, the law of least squares recognizes the possibility of any error positive or negative, however great, although the probability of indefinitely great errors will be indefinitely small. It occurred to me that in the case of the emersion of a star from an occultation, since it was impossible to strike the chronograph-key too early, while it might be struck indefinitely too late, the law of least squares could hardly apply, and I have made some experiments upon this point, which I will narrate in detail at the end of this paper, merely remarking in this place that the divergence from the theoretical law proved to be insignificant. On the other hand, there are many cases in which we have no reason to expect that the errors will vary according to the least-squares curve. Let us consider, for example, a chemical analysis. Here the error is generally not due to the combined action of a very great number of very small causes, but, on the contrary, there are generally two or three leading causes of error, depending upon some defect in the theory of the analysis or on some error in the manipulation, which is likely to result from a single one, such as cannot be regarded as in any way compounded of a large number of independent parts. Thus, a drop may be spilled or a portion thrown out of the crucible too small to be detected, but the whole drop is spilled at once, or the whole portion goes at once. In very exact analysis, in which such causes are almost altogether eliminated, the remaining and chief cause of error will be an error of weighing, due to a want of delicacy of the balance, and will be of the same nature as an error of computation, due to the fact that the number of decimal places used has been limited. The method of considering such errors is treated by Dr. Bremiker, in the preface to his "Tabula Logarithmorum Sex Decimalium," a work to which the attention of chemists ought to be drawn. When the law of facility of errors cannot be deduced *a priori* from the consideration of the causes to which it is due, a large number of experimental observations must be made upon a known quantity in order to find in what manner the errors vary, or the same series of observations may be used both to determine what the value of the unknown quantity is and also what the law of the variation of errors is. Thus, in the method of least squares, h is to be determined empirically, and the common way of doing it is to use the actual observations by which the unknown quantity is determined to determine also the value of h. In doing this, it should be remembered that a precise and trustworthy determination can only be obtained from a large number of observations. This procedure amounts, in fact, to adding an additional unknown quantity, a very obvious fact, and yet one which is habitually overlooked. Encke, in his "Astronomisches Jahrbuch" for 1834, has given the most complete formulæ that I have anywhere found for determining the value of h, as well as its uncertainty. These formulæ require correction on account of the circumstance just mentioned. They should be as follows:

When it is necessary to combine, by least squares, observations of different orders of precision, they are weighted proportionately to $h^2$. If we have two series of observations, one of which is as accurate as you please, and the other as inaccurate as you please, a better result than that which the most accurate series of measures gives can always be got by combining with it the least accurate series, provided the proper weights are given to the two series. This proposition seems paradoxical, and is not admitted by many very competent heads, but I cannot see how the conclusion can possibly be evaded. It does not depend at all upon any of the peculiar principles induced by the method of least squares, but rests on the fundamental axioms of probabilities. Indeed, it may conveniently be based directly upon the principles of logic itself. The least accurate series of measures offers certain facts, which may be used as premises, and it cannot be that if those facts are properly used they leave us in greater ignorance than we were before. Additional facts must increase our knowledge, if the proper inferences are made from them, and, therefore, an additional series of observations, if it have any weight at all, must, if its proper weight be assigned to it, improve the value of the unknown quantity. On the other hand, when it is considered that there is an uncertainty in the value of h, it may be that if the two series of observations differ greatly in accuracy, and the value of h is not determined with much precision, it may be better at once to take the result of the best series of observations than to combine the two series with the best weights that we are able to give.

Let—

$x_i$ be the value from any set of observations;
$\varepsilon_i$ the mean error of this set;
$g_i\,\varepsilon_i$ the mean error of $\varepsilon_i$;
$w_i$ the true weight;
E the mean error of weight *one;* and
x the truly weighted mean.

$$x = \frac{\Sigma_i (w_i\, x_i)}{\Sigma_i\, w_i}$$

The best approximation we can get to x will be subject to two kinds of error: first, those arising from errors of $x_i$; and, secondly, those arising from errors in our assumed values of $\varepsilon_i$, from which we derive $w_i$ by the formula,

$$w_i = \frac{E^2}{\varepsilon_i^{\,2}}$$

The mean error of $w_i$ will be $w_i^2\, g_i^2$

$$D_{x_2}\, x = \frac{w_2}{\Sigma_i\, w_i}$$

$$D_{w_i}\, x = \frac{x_i\, \Sigma_i\, w_i - \Sigma_i\, w_i\, x}{(\Sigma_i\, w_i)^2} = \frac{x_i - x}{\Sigma_i\, w_i}$$

Then we have—

$$\varepsilon^2 = \Sigma_i \left( \frac{x_i - x}{\Sigma_i\, w_i} \right)^2 w_i^2\, g_i^2 + \Sigma_i \left( \frac{w_i}{\Sigma_i\, w_i} \right)^2 \varepsilon_i^{\,2} = \frac{\Sigma_i\,(x_i - x)^2\, w_i\, g_i^2 + E^2\, \Sigma_i\, w_i}{(\Sigma_i\, w_i)^2}$$

These are the two common rules by which $\varepsilon$ may be calculated. Call their results $\varepsilon'$ and $\varepsilon''$, so that—

$$\varepsilon' = \frac{E}{\sqrt{\Sigma_i\, w_i}}$$

$$\varepsilon'' = \sqrt{\frac{\Sigma_i\, w_i\,(x_i - x)^2}{(m-1)\, \Sigma_i\, w_i}}$$

where m is the number of determinations.

The first gives—

$$\varepsilon^2 = \varepsilon'^{\,2} + \frac{\Sigma_i\,(x_i - x)^2\, w_i^2\, g_i^2}{(\Sigma_i\, w_i)^2}$$

If $m = 2$,

$$(x_1 - x) = x_i - \frac{w_1\, x_1 + w_2\, x_2}{w_1 + w_2} = \frac{w_2}{w_1 + w_2} x_1 - x_2$$

$$x_2 - x = - \frac{w_1}{w_1 + w_2} (x_1 - x_2)$$

$$\varepsilon^2 = \varepsilon'^{\,2} + \frac{w_1^2\, w_2^2}{(w_1 + w_2)^4} (g_1^2 + g_2^2)(x_1 - x_2)^2$$

Put $\frac{w_2}{w_1} = r$,

$$\varepsilon^2 = \varepsilon'^{\,2} + \frac{r^2}{(1+r)^4} (g_1^2 + g_2^2)(x_1 - x_2)^2$$

$$\varepsilon'' = \sqrt{\frac{w_1\, w_2^2 + w_1^2\, w_2}{(w_1 + w_2)^3}\,(x_1 - x_2)^2} = \sqrt{\frac{w_1\, w_2}{(w_1 + w_2)^2}\,(x_1 - x_2)^2}$$

$$\varepsilon''^{\,2} = \frac{w_1\, w_2}{(w_1 + w_2)^2} (x_1 - x_2)^2 = \frac{r}{(1+r)^2} (x_1 - x_2)^2$$

$$\varepsilon^2 = \varepsilon'^{\,2} + \frac{r}{(1+r)^2} (g_1^2 + g_2^2)\, \varepsilon''^{\,2}$$

Now, suppose $\varepsilon^2 < \varepsilon_1^2 < \varepsilon_2^2$; then $r < 1$; then—

$$\varepsilon_1^2 > \varepsilon'^2 + \frac{r}{(1+r)^2}(g_1^2 + g_2^2)\,\varepsilon''^2$$

But—

$$\varepsilon' = \varepsilon_1 \sqrt{\frac{w_1}{w_1 + w_2}} = \frac{\varepsilon_1}{\sqrt{1+r}} = \varepsilon_2 \sqrt{\frac{r}{1+r}}$$

$$\varepsilon'^2 = \varepsilon_1^2 \frac{1}{1+r} = \varepsilon_2^2 \frac{r}{1+r}\,.$$

$$\frac{\varepsilon_2^1}{\varepsilon_2^2} = \frac{w_2}{w_1} = r$$

$$\varepsilon_1^2 = r\,\varepsilon_2^2$$

$$\varepsilon_1^2 - \varepsilon'^2 = \varepsilon_1^2 \frac{r}{1+r}$$

$$\varepsilon_1^2 \frac{r}{1+r} > \frac{r}{1+r^2}(g_1^2 + g_2^2)\,\varepsilon''^2$$

$$\frac{\varepsilon_1^2}{\varepsilon''^2}(1+r) > (g_1^2 + g_2^2)$$

$$\varepsilon_2^2\,r = \varepsilon_1^2$$

$$r\,\frac{\varepsilon_2^2}{\varepsilon''^2}(1+r) > (g_1^2 + g_2^2)$$

$$r\,\frac{\varepsilon_1^2 + \varepsilon_2^2}{\varepsilon''^2} > g^1{}_2 + g_2^2$$

Unless this condition is satisfied, the combination is worse than the best determination.

It is generally admitted that $m_i$ being the number of observations from which $\varepsilon_i$ has been determined,

$$g_i = \frac{1}{\sqrt{2m_i}}$$

Then the condition is—

$$2r\,\frac{\varepsilon_1^2 + \varepsilon_2^2}{\varepsilon''^2} > \frac{1}{m_1} + \frac{1}{m_2}$$

or we may write—

$$\frac{\varepsilon_1^2 + \varepsilon_2^2}{(x_1 - x_2^2)} > \frac{g_1^2 + g_2^2}{(1+r)^2}$$

or—

$$\frac{\varepsilon_1^2 + \varepsilon_2^2}{(x_1 - x_2)^2}(1+r)^2 > \frac{\frac{1}{m_1} + \frac{1}{m_2}}{2}$$

or we may write—

$$\frac{\frac{(x_1 - x)^2}{\varepsilon_1^2} + \frac{(x_2 - x)^2}{\varepsilon_2^2}}{\frac{1}{\varepsilon^2} + \frac{1}{\varepsilon_2^2}} < \frac{-4\,\varepsilon_1^2}{\frac{1}{m_1} + \frac{1}{m_2}}$$

Some writers upon the subject have wished to assign a smaller weight to those observations which differ largely from the mean than to those which come close to it. They have reasoned as if h, or the precision of an observation, were something which belonged to a single observation; whereas, in fact, it is a statistical quantity altogether, and belongs only to an observation as a member of a certain series. We may have a large series of observations for which h has a certain value, and those observations may perhaps be separated into two series on some principle or other for which h shall have two different values, and if this can be done there is an advantage in doing it. It is, in fact, limiting our universe. In probabilities generally h is a mean or probable quantity for a series of observations, and if we can divide our universe into two parts, getting different values of h, it will be an increase of knowledge to do so. For example, suppose that some of the observations were taken under one set of circumstances and the rest under another set of circumstances. That would afford a principle upon which the observations could be distinguished, and if the value of h for the two sets turned out different, it would be an advantage to separate them and to give them different weights. Now, the degree of discordance of observations from the most probable value of the unknown quantity may be taken as a means of estimating the relative degrees of care, &c., used in making them, and so to discriminate between them. But it would certainly be very absurd to allow no weight to the fact that we have endeavored to make them all with equal care. It must never be forgotten that h is a statistical quantity; not one which belongs to a single observation, but one which belongs to an infinite series of observations.

It is entirely in accordance with the method of least squares to reject discordant observations, and this has always been done, even by those who object to an exact criterion for determining what observations should be rejected. For example, Mr. Glaisher says that no observation should be rejected excepting obvious mistakes, thereby admitting that it is proper sometimes to reject observations, and nobody is more opposed to the rejection of observations than he. But no line of demarkation can be drawn between mistakes which are obvious and mistakes which are not obvious. In some cases it may be obvious that 53 has been written by the recorder instead of 35. In other cases it may be doubtful whether it ought to be called an obvious mistake or whether there may be some doubt hanging over it, and there is every grade of probability, from the greatest to the least; and when we examine into the facts of observation, and do not attempt to make our way through a vacuous space of pure theory, it will be found that the occasional rejection of observations is justified from every point of view; and if observations are to be rejected, exact criteria are necessary to determine upon principles of probabilities in what cases they should be rejected. The criterion of Professor Peirce is the only one which conforms rigidly to those principles, and, indeed, I am not aware that it has been attacked upon the ground of not conforming to the principles of probabilities, although it has been attacked on the ground that no such criterion should be used, and that no observation should be rejected except upon principles of guesswork, for that is what it amounts to to say that none but obvious mistakes should be rejected. Experience has shown that the errors which this criterion rejects are almost precisely those which a person of sound judgment would pronounce to be obvious mistakes, but some other criteria have been proposed, which are confessedly inexact, but which have the advantage of involving less calculation, but these are no better than the unaided judgment of an experienced person, and in some cases not so good.

*Account of the experiments.*

These experiments were made in order to study the distribution of errors in the observation of a phenomenon not seen coming on, as in the case of a transit, but sudden, as in the case of the emersion of a star from behind the moon. The time was noted upon a Hipp chronoscope, which is a modification of an invention of Wheatstone's. The train of clock-work moved by weight is regulated by the vibration of a little spring or reed striking against a toothed wheel a thousand times a second. There are two hands, one of which marks tenths of a second, and the other thousandths of a second. These hands are thrown into gear when the first event occurs, and out of gear when the second event occurs, so that the amount that they have moved measures the interval. The manner in which they are thrown in and out of gear is this: The axis of one of the wheels of the main train is hung, and the axis of one of the wheels of the hand-gearing passes completely through it and comes out behind, where it rests upon a spring, which spring is influenced by an electro-magnet. There are two crown-wheels, one upon the hollow axis belonging to the main train already mentioned, the other facing it at a very small distance from it, and fixed in position and upon the axis of the wheel belonging to the hand-gearing, which moves backward and forward inside, and the other axis as described. There is a little arm, which will catch in the teeth of one or other of these crown-wheels. Before the first event it is in the teeth of the fixed crown-wheel, which thus prevents the hands from turning round. When the first event occurs this arm is thrown forward into the teeth of the rapidly rotating crown-wheel, and thus the hands begin to turn round. When the second event occurs the arm is thrown into the teeth of the first crown-wheel, and so the hands are suddenly stopped.

It will be observed that although the instrument only registers to thousandths of a second, yet if an event can be repeated many times with a variation of time much smaller than that, the instrument ought, theoretically, in the mean of a large number of observations, to give a much closer result than 0.001 second; for when the first event occurs, and the arm is thrown into the moving crown-wheel, it probably will not strike exactly in any catch, but will strike on the inclined side of a tooth. If it strikes on the forward side of the tooth, the hands will be carried forward by the fraction of a thousandth of a second more as the arm glides down this side to the bottom of the catch. But if it strikes on the back side of the tooth, the hands will be carried relatively back the fraction of the thousandth part of a second as the arm glides back to the bottom of the catch. Now, if the top of the tooth is midway between the bottom of two catches, it is equally likely to be carried forward or back. The same thing occurs when the second event happens and the arm strikes upon the fixed crown-wheel. An error in the marked interval will thus result, which error may amount to —0.001 second in the extreme, or to + 0.001 second, and any one error between these limits is as likely as any other; consequently, these errors, being entirely incidental and independent of one another, they will balance one another in the mean of a large number of observations, and thus a much higher degree of accuracy may be reached. This, however, is a matter which has no influence on the experiments which I have made, inasmuch as the interval measured by me was a variable one, and in point of fact I have never been able to make the instrument work with such nicety as to measure much closer than 0.001 second. In the descriptions of this instrument which I have seen, only two instrumental corrections have been mentioned; one is owing to the rate with which the instrument goes, and the other is with reference to the time occupied by the arm in passing from one crown-wheel to the other. To determine these two constants, a little apparatus accompanies the instrument, by which the time of the fall of a ball from different heights may be registered, and by registering the time from two different heights these two corrections, one of which is proportional to the time and the other is a constant, may be determined. The ball is held in a pair of jaws; when these jaws separate, the contact is broken, the hands begin to move, and the ball begins to fall. Care should be taken that the ball is so small that the jaws cannot be separated for any appreciable time before the ball is free to fall, but if the spring with which they open is sufficiently strong the ball may fall freely from the very first. At the bottom the ball strikes upon a platform made of wood and covered with green cloth, and it throws this platform down upon two metallic springs below it, through which contact is made again, so that the hand stops, and then the platform is held down by a catch.

As the instrument came from the makers it was found that when the ball struck upon the platform it threw one of the springs down, so that the contact was made, and then immediately interrupted before there was time for the hand to stop, so that a slight error of about 0.001 second arose in this way. This was usually corrected by putting little wooden wedges beneath these springs, so that they could not be thrown down in this way. In order further to test the instrument, I made use of a break-circuit chronometer, and measured the interval of two seconds upon the instrument for this purpose. It was necessary to employ two telegraph-repeaters. There are two ways in which this can be arranged, so as to correct a break-circuit chronometer with a Hipp chronoscope. It is sufficient to describe one of them. The arrangement is shown in the accompanying figure:

Bat. is the battery; Ch., the chronoscope; Chr., the chronometer; R., a resistance-coil; and I and II, two telegraph-repeaters. I is a common telegraph-repeater, with the non-conducting screw so far raised that when the armature once flies up the magnet cannot bring it down again. F is the magnet end of this repeater; B, the end at the second circuit. When the first circuit is broken the armature flies up and instantly breaks the second circuit. H is arranged differently from common repeaters. As long as there is a current through the first circuit and the armature is held down, there is no connection in the second circuit. When the first circuit is broken, the armature, under the influence of a very strong spring, flies up for a distance of a tenth of a millimeter, and there makes the connection in the second circuit.

This repeater can be extemporized out of a common relay. The resistance-coil should always be used in connection with the chronoscope in such a way that when the circuit is broken in the first place the current shall be so weak as just to be able to hold the hands still, while when it is made again the current shall be so strong as to make the circuit as quickly as possible.

The rate as given by the break-circuit chronometer did not agree with that found by the fall-apparatus, and indeed there was a slight discrepancy in the rate given by the latter for different heights of fall. Professor J. E. Oliver suggested to me that this discrepancy was due to a retardation of the instrument when the hands were geared in, which took place somewhat gradually, and I found that this was the case, and that the ear could detect that when the hands were geared in, during the space of three-fourths of a second, the note produced by the vibration of the reed was lowered about the sixth of a tone. The supposition that this took place uniformly sufficiently accounted for all the discrepancy, and this gave me two more instrumental constants, viz: the amount of retardation on gearing in the hands, and the time during which that retardation was brought about. With this instrument as well as with the other chronometer I made a large number of experiments upon the time occupied in answering signals of various kinds, such as the emission of points upon paper from behind a screen, the appearance of induction-sparks from a Ruhmkorff coil, flashes of light thrown upon a screen, sudden changes from one magic-lantern figure to another, &c., the general result of which was to confirm the facts already in our possession, and which are due to the researches of Hirsch, Daumbusch, and others. But there was one series of experiments which deserves particular description. I employed a young man about eighteen years of age, who had had no previous experience whatever in observations, to answer a signal consisting of a sharp sound like a rap, the answer being made upon a telegraph-operator's key nicely adjusted. Five hundred observations were made on every week-day during a month, twenty-four days' observations in all. The results are given in the accompanying table, and are also shown upon plate No. 27. On this plate the abscissæ represent the interval of time between the signal and the answer as indicated on the Hipp chronoscope, the ordinates measure the number of observations, which were subject to a large amount of error. The curve has, however, not been plotted directly from the observations, but after they have been smoothed off by the addition of adjacent numbers in the table eight times over, so as to diminish the irregularities of the curve. The smoother curve on the figures is a mean curve for every day drawn by eye so as to eliminate the irregularities entirely. It was found that after the first two or three days the curve differed very little from that derived from the theory of least squares. It will be noticed that on the first day, when the observer was entirely inexperienced, the observations scattered to such an extent that I have been obliged to draw the curve upon a different scale from that adopted for the other days. It will also be seen that the personal equation from the mean amount by which the answer came too late rapidly decreased for the first five days, until it was about one seventh of a second, and that it then gradually increased until the twelfth day, when it amounted to about 0.22 seconds. But while the personal equation was thus first diminishing and afterward increasing, the probable error or range of errors was constantly decreasing after the twelfth day. There was some variation in the personal equation, but not much, but the range of errors continually decreased as long as the observations lasted, and so remarkably that for the twenty-fourth day the probable error does not exceed one-eightieth of a second. I think that this clearly demonstrates the value of such practice in training the nerves for observation, for it can hardly be supposed that the best observer has so small a range of error as this, and I would therefore recommend that transit-observers be kept in constant training by means of some observations of an artificial event which can be repeated with rapidity, so that several hundred can be taken daily without great labor, and I do not think that it is essential that these observations should very closely imitate the transit of a star over wires, inasmuch as it is the general condition of the nerves which it is important to keep in training more than anything peculiar to this or that kind of observation.

## *Details of the experiments.*

FIRST DAY, JULY 1, 1872.

| Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 158 | 1 | 348 | 0 | 389 | 1 | 430 | 0 | 471 | 1 | 512 | 1 | 553 | 0 | 593 | 1 | 633 | 2 |
| 240 | 1 | 9 | 1 | 390 | 3 | 1 | 2 | 2 | 4 | 3 | 2 | 4 | 1 | 4 | 1 | 4 | 1 |
| 261 | 1 | 350 | 0 | 1 | 2 | 2 | 0 | 3 | 4 | 4 | 2 | 5 | 1 | 5 | 0 | 5 | 1 |
| 277 | 1 | 1 | 0 | 2 | 3 | 3 | 3 | 4 | 2 | 5 | 3 | 6 | 2 | 6 | 0 | 6 | 3 |
| 296 | 1 | 2 | 0 | 3 | 4 | 4 | 2 | 5 | 1 | 6 | 2 | 7 | 2 | 7 | 1 | 7 | 1 |
| 312 | 1 | 3 | 1 | 4 | 2 | 5 | 1 | 6 | 2 | 7 | 1 | 8 | 0 | 8 | 0 | 8 | 1 |
| 3 | 0 | 4 | 2 | 5 | 1 | 6 | 5 | 7 | 1 | 8 | 0 | 9 | 1 | 9 | 1 | 9 | 0 |
| 4 | 0 | 5 | 2 | 6 | 4 | 7 | 1 | 8 | 3 | 9 | 2 | 560 | 3 | 600 | 1 | 640 | 0 |
| 5 | 1 | 6 | 0 | 7 | 2 | 8 | 2 | 9 | 1 | 520 | 1 | 1 | 1 | 1 | 0 | 1 | 0 |
| 6 | 1 | 7 | 1 | 8 | 0 | 9 | 0 | 480 | 5 | 1 | 0 | 2 | 1 | 2 | 2 | 2 | 0 |
| 7 | 0 | 8 | 2 | 9 | 3 | 440 | 2 | 1 | 2 | 2 | 0 | 3 | 0 | 3 | 0 | 3 | 0 |
| 8 | 0 | 9 | 1 | 400 | 1 | 1 | 3 | 2 | 1 | 3 | 1 | 4 | 0 | 4 | 0 | 4 | 0 |
| 9 | 0 | 360 | 0 | 1 | 3 | 2 | 1 | 3 | 0 | 4 | 0 | 5 | 2 | 5 | 0 | 5 | 0 |
| 320 | 0 | 1 | 3 | 2 | 0 | 3 | 1 | 4 | 4 | 5 | 3 | 6 | 0 | 6 | 1 | 6 | 1 |
| 1 | 2 | 2 | 3 | 3 | 0 | 4 | 1 | 5 | 2 | 6 | 1 | 7 | 2 | 7 | 0 | 7 | 0 |
| 2 | 0 | 3 | 2 | 4 | 3 | 5 | 3 | 6 | 2 | 7 | 1 | 8 | 0 | 8 | 1 | 8 | 0 |
| 3 | 1 | 4 | 1 | 5 | 2 | 6 | 3 | 7 | 0 | 8 | 2 | 9 | 1 | 9 | 1 | 9 | 0 |
| 4 | 1 | 5 | 0 | 6 | 2 | 7 | 5 | 8 | 1 | 9 | 1 | 570 | 1 | 610 | 0 | 650 | 0 |
| 5 | 2 | 6 | 2 | 7 | 2 | 8 | 2 | 9 | 6 | 530 | 2 | 1 | 1 | 1 | 1 | 1 | 0 |
| 6 | 0 | 7 | 3 | 8 | 3 | 9 | 1 | 490 | 2 | 1 | 2 | 2 | 2 | 2 | 0 | 2 | 2 |
| 7 | 0 | 8 | 1 | 9 | 3 | 450 | 1 | 1 | 0 | 2 | 1 | 3 | 0 | 3 | 0 | 3 | 0 |
| 8 | 0 | 9 | 1 | 410 | 2 | 1 | 1 | 2 | 6 | 3 | 2 | 4 | 1 | 4 | 0 | 4 | 0 |
| 9 | 0 | 370 | 1 | 1 | 3 | 2 | 1 | 3 | 2 | 4 | 0 | 5 | 0 | 5 | 0 | 5 | 0 |
| 330 | 0 | 1 | 1 | 2 | 3 | 3 | 2 | 4 | 0 | 5 | 3 | 6 | 1 | 6 | 1 | 6 | 0 |
| 1 | 0 | 2 | 1 | 3 | 1 | 4 | 2 | 5 | 1 | 6 | 0 | 7 | 1 | 7 | 0 | 7 | 0 |
| 2 | 1 | 3 | 0 | 4 | 4 | 5 | 3 | 6 | 2 | 7 | 1 | 8 | 1 | 8 | 0 | 8 | 0 |
| 3 | 0 | 4 | 1 | 5 | 3 | 6 | 3 | 7 | 3 | 8 | 1 | 9 | 2 | 9 | 0 | 9 | 1 |
| 4 | 0 | 5 | 1 | 6 | 6 | 7 | 2 | 8 | 2 | 9 | 2 | 580 | 1 | 620 | 1 | 660 | 1 |
| 5 | 0 | 6 | 0 | 7 | 2 | 8 | 2 | 9 | 2 | 540 | 3 | 1 | 2 | 1 | 1 | 1 | 0 |
| 6 | 0 | 7 | 2 | 8 | 2 | 9 | 1 | 500 | 0 | 1 | 3 | 2 | 0 | 2 | 1 | 2 | 0 |
| 7 | 2 | 8 | 1 | 9 | 2 | 460 | 3 | 1 | 3 | 2 | 1 | 3 | 3 | 3 | 2 | 3 | 0 |
| 8 | 0 | 9 | 1 | 420 | 2 | 1 | 6 | 2 | 3 | 3 | 1 | 4 | 2 | 4 | 0 | 4 | 1 |
| 9 | 1 | 380 | 1 | 1 | 1 | 2 | 1 | 3 | 5 | 4 | 1 | 5 | 0 | 5 | 1 | 682 | 1 |
| 340 | 0 | 1 | 1 | 2 | 0 | 3 | 3 | 4 | 0 | 5 | 0 | 6 | 2 | 6 | 1 | 692 | 1 |
| 1 | 0 | 2 | 0 | 3 | 3 | 4 | 1 | 5 | 2 | 6 | 1 | 7 | 1 | 7 | 0 | 732 | 1 |
| 2 | 1 | 3 | 0 | 4 | 2 | 5 | 1 | 6 | 4 | 7 | 0 | 8 | 0 | 8 | 2 | 748 | 1 |
| 3 | 1 | 4 | 1 | 5 | 4 | 6 | 3 | 7 | 6 | 8 | 2 | 9 | 1 | 9 | 0 | 757 | 1 |
| 4 | 2 | 5 | 0 | 6 | 3 | 7 | 6 | 8 | 4 | 9 | 2 | 590 | 1 | 630 | 0 | 900 | 1 |
| 5 | 2 | 6 | 4 | 7 | 0 | 8 | 4 | 9 | 1 | 550 | 1 | 1 | 2 | 1 | 1 | 919 | 1 |
| 6 | 0 | 7 | 2 | 8 | 4 | 9 | 4 | 510 | 2 | 1 | 1 | 592 | 2 | 632 | 2 | 978 | 1 |
| 347 | 3 | 388 | 1 | 429 | 2 | 470 | 4 | 511 | 0 | 552 | 2 | | | | | | |

*Details of the experiments.*—Continued.

SECOND DAY, JULY 5, 1872.

| Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 97 | 1 | 176 | 3 | 203 | 3 | 230 | 8 | 257 | 3 | 283 | 1 | 309 | 1 | 335 | 0 | 361 | 1 |
| 106 | 1 | 7 | 1 | 4 | 4 | 1 | 10 | 8 | 7 | 4 | 5 | 310 | 0 | 6 | 1 | 2 | 0 |
| 119 | 1 | 8 | 1 | 5 | 3 | 2 | 6 | 9 | 2 | 5 | 0 | 1 | 0 | 7 | 0 | 3 | 1 |
| 124 | 1 | 9 | 2 | 6 | 1 | 3 | 5 | 260 | 3 | 6 | 1 | 2 | 0 | 8 | 0 | 4 | 0 |
| 127 | 1 | 180 | 2 | 7 | 4 | 4 | 1 | 1 | 2 | 7 | 0 | 3 | 2 | 9 | 1 | 5 | 0 |
| 129 | 1 | 1 | 2 | 8 | 4 | 5 | 5 | 2 | 3 | 8 | 4 | 4 | 2 | 340 | 0 | 6 | 2 |
| 134 | 1 | 2 | 1 | 9 | 3 | 6 | 3 | 3 | 5 | 9 | 0 | 5 | 0 | 1 | 0 | 7 | 0 |
| 136 | 1 | 3 | 1 | 210 | 3 | 7 | 7 | 4 | 5 | 290 | 1 | 6 | 2 | 2 | 0 | 8 | 0 |
| 139 | 1 | 4 | 0 | 1 | 6 | 8 | 7 | 5 | 1 | 1 | 2 | 7 | 1 | 3 | 0 | 9 | 1 |
| 140 | 1 | 5 | 2 | 2 | 4 | 9 | 7 | 6 | 3 | 2 | 1 | 8 | 3 | 4 | 1 | 370 | 0 |
| 144 | 1 | 6 | 0 | 3 | 5 | 240 | 6 | 7 | 2 | 3 | 1 | 9 | 1 | 5 | 0 | 1 | 0 |
| 153 | 1 | 7 | 1 | 4 | 4 | 1 | 1 | 8 | 8 | 4 | 1 | 320 | 0 | 6 | 2 | 2 | 0 |
| 154 | 1 | 8 | 2 | 5 | 4 | 2 | 2 | 9 | 1 | 5 | 0 | 1 | 0 | 7 | 0 | 3 | 0 |
| 155 | 1 | 9 | 0 | 6 | 7 | 3 | 3 | 270 | 3 | 6 | 4 | 2 | 1 | 8 | 0 | 4 | 0 |
| 159 | 1 | 190 | 1 | 7 | 4 | 4 | 6 | 1 | 3 | 7 | 4 | 3 | 0 | 9 | 0 | 5 | 0 |
| 164 | 1 | 1 | 2 | 8 | 8 | 5 | 4 | 2 | 3 | 8 | 1 | 4 | 0 | 350 | 1 | 6 | 0 |
| 5 | 1 | 2 | 4 | 9 | 2 | 6 | 7 | 3 | 1 | 9 | 3 | 5 | 0 | 1 | 0 | 7 | 0 |
| 6 | 0 | 3 | 2 | 220 | 7 | 7 | 3 | 4 | 1 | 300 | 5 | 6 | 1 | 2 | 3 | 8 | 0 |
| 7 | 1 | 4 | 1 | 1 | 7 | 8 | 4 | 5 | 0 | 1 | 1 | 7 | 1 | 3 | 0 | 9 | 1 |
| 8 | 1 | 5 | 4 | 2 | 3 | 9 | 2 | 6 | 2 | 2 | 3 | 8 | 0 | 4 | 0 | 380 | 0 |
| 9 | 0 | 6 | 1 | 3 | 7 | 250 | 5 | 7 | 2 | 3 | 0 | 9 | 0 | 5 | 1 | 1 | 1 |
| 170 | 1 | 7 | 4 | 4 | 6 | 1 | 1 | 8 | 2 | 4 | 1 | 330 | 0 | 6 | 0 | 2 | 0 |
| 1 | 0 | 8 | 3 | 5 | 3 | 2 | 7 | 9 | 5 | 5 | 2 | 1 | 0 | 7 | 0 | 3 | 1 |
| 2 | 2 | 9 | 3 | 6 | 4 | 3 | 5 | 280 | 3 | 6 | 1 | 2 | 0 | 8 | 0 | 4 | 1 |
| 3 | 0 | 200 | 2 | 7 | 2 | 4 | 5 | 1 | 1 | 7 | 2 | 3 | 0 | 9 | 1 | 5 | 1 |
| 4 | 0 | 1 | 6 | 8 | 2 | 5 | 6 | 282 | 1 | 308 | 3 | 331 | 0 | 360 | 0 | 386 | 1 |
| 175 | 6 | 202 | 7 | 229 | 9 | 256 | 3 | | | | | | | | | | |

THIRD DAY, JULY 6, 1872.

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 90 | 2 | 142 | 1 | 164 | 2 | 186 | 4 | 208 | 5 | 229 | 3 | 250 | 0 | 271 | 1 | 292 | 1 |
| 106 | 1 | 3 | 1 | 5 | 3 | 7 | 4 | 9 | 4 | 230 | 2 | 1 | 1 | 2 | 2 | 3 | 1 |
| 111 | 1 | 4 | 3 | 6 | 3 | 8 | 2 | 210 | 3 | 1 | 6 | 2 | 2 | 3 | 0 | 4 | 0 |
| 113 | 1 | 5 | 1 | 7 | 5 | 9 | 2 | 1 | 4 | 2 | 4 | 3 | 5 | 4 | 2 | 5 | 1 |
| 124 | 2 | 6 | 3 | 8 | 2 | 190 | 2 | 2 | 3 | 3 | 2 | 4 | 1 | 5 | 1 | 6 | 0 |
| 5 | 2 | 7 | 5 | 9 | 5 | 1 | 6 | 3 | 1 | 4 | 3 | 5 | 2 | 6 | 1 | 7 | 0 |
| 6 | 2 | 8 | 5 | 170 | 4 | 2 | 4 | 4 | 9 | 5 | 2 | 6 | 2 | 7 | 0 | 8 | 0 |
| 7 | 2 | 9 | 2 | 1 | 8 | 3 | 5 | 5 | 9 | 6 | 2 | 7 | 2 | 8 | 1 | 9 | 0 |
| 8 | 2 | 150 | 4 | 2 | 1 | 4 | 10 | 6 | 5 | 7 | 1 | 8 | 2 | 9 | 0 | 300 | 0 |
| 9 | 0 | 1 | 7 | 3 | 3 | 5 | 10 | 7 | 1 | 8 | 4 | 9 | 4 | 280 | 1 | 1 | 0 |
| 130 | 1 | 2 | 2 | 4 | 4 | 6 | 1 | 8 | 2 | 9 | 3 | 260 | 1 | 1 | 1 | 2 | 0 |
| 1 | 0 | 3 | 0 | 5 | 6 | 7 | 4 | 9 | 7 | 240 | 2 | 1 | 2 | 2 | 3 | 3 | 1 |
| 2 | 2 | 4 | 3 | 6 | 2 | 8 | 5 | 220 | 3 | 1 | 1 | 2 | 1 | 3 | 1 | 318 | 1 |
| 3 | 0 | 5 | 1 | 7 | 3 | 9 | 10 | 1 | 4 | 2 | 3 | 3 | 2 | 4 | 0 | 323 | 1 |
| 4 | 1 | 6 | 1 | 8 | 6 | 200 | 8 | 2 | 7 | 3 | 1 | 4 | 1 | 5 | 1 | 347 | 1 |
| 5 | 0 | 7 | 5 | 9 | 2 | 1 | 3 | 3 | 5 | 4 | 0 | 5 | 3 | 6 | 0 | 356 | 1 |
| 6 | 2 | 8 | 1 | 180 | 6 | 2 | 4 | 4 | 3 | 5 | 3 | 6 | 0 | 7 | 1 | 364 | 1 |
| 7 | 0 | 9 | 3 | 1 | 5 | 3 | 4 | 5 | 2 | 6 | 4 | 7 | 0 | 8 | 0 | 365 | 1 |
| 8 | 1 | 160 | 4 | 2 | 2 | 4 | 4 | 6 | 5 | 7 | 2 | 8 | 1 | 9 | 1 | 381 | 1 |
| 9 | 1 | 1 | 6 | 3 | 2 | 5 | 8 | 7 | 8 | 8 | 1 | 9 | 1 | 290 | 0 | 445 | 1 |
| 140 | 3 | 2 | 1 | 4 | 8 | 6 | 4 | 228 | 3 | 249 | 1 | 270 | 0 | 291 | 1 | 452 | 1 |
| 141 | 1 | 163 | 3 | 185 | 2 | 207 | 5 | | | | | | | | | | |

### *Details of the experiments*—Continued.

FOURTH DAY, JULY 8, 1872.

| Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 65 | 1 | 148 | 1 | 169 | 2 | 190 | 6 | 211 | 10 | 231 | 3 | 251 | 1 | 271 | 2 | 291 | 0 |
| 97 | 1 | 9 | 1 | 170 | 4 | 1 | 9 | 2 | 6 | 2 | 5 | 2 | 2 | 2 | 1 | 2 | 0 |
| 111 | 2 | 150 | 0 | 1 | 7 | 2 | 9 | 3 | 9 | 3 | 3 | 3 | 2 | 3 | 2 | 3 | 0 |
| 126 | 1 | 1 | 1 | 2 | 5 | 3 | 4 | 4 | 8 | 4 | 3 | 4 | 1 | 4 | 0 | 4 | 1 |
| 131 | 1 | 2 | 2 | 3 | 4 | 4 | 7 | 5 | 6 | 5 | 3 | 5 | 1 | 5 | 0 | 5 | 0 |
| 2 | 0 | 3 | 2 | 4 | 5 | 5 | 9 | 6 | 1 | 6 | 3 | 6 | 2 | 6 | 0 | 6 | 0 |
| 3 | 0 | 4 | 1 | 5 | 3 | 6 | 5 | 7 | 6 | 7 | 2 | 7 | 0 | 7 | 1 | 7 | 2 |
| 4 | 1 | 5 | 2 | 6 | 6 | 7 | 6 | 8 | 1 | 8 | 3 | 8 | 0 | 8 | 0 | 8 | 0 |
| 5 | 1 | 6 | 0 | 7 | 10 | 8 | 5 | 9 | 5 | 9 | 2 | 9 | 2 | 9 | 1 | 9 | 2 |
| 6 | 0 | 7 | 3 | 8 | 4 | 9 | 5 | 220 | 5 | 240 | 3 | 260 | 1 | 280 | 0 | 314 | 1 |
| 7 | 0 | 8 | 0 | 9 | 4 | 200 | 10 | 1 | 5 | 1 | 1 | 1 | 2 | 1 | 0 | 319 | 1 |
| 8 | 1 | 9 | 5 | 180 | 2 | 1 | 12 | 2 | 5 | 2 | 1 | 2 | 0 | 2 | 0 | 323 | 1 |
| 9 | 0 | 160 | 2 | 1 | 1 | 2 | 8 | 3 | 4 | 3 | 1 | 3 | 4 | 3 | 1 | 327 | 1 |
| 140 | 0 | 1 | 3 | 2 | 8 | 3 | 6 | 4 | 8 | 4 | 1 | 4 | 3 | 4 | 0 | 343 | 1 |
| 1 | 1 | 2 | 2 | 3 | 13 | 4 | 10 | 5 | 3 | 5 | 0 | 5 | 0 | 5 | 0 | 347 | 1 |
| 2 | 0 | 3 | 1 | 4 | 10 | 5 | 6 | 6 | 4 | 6 | 1 | 6 | 0 | 6 | 0 | 352 | 1 |
| 3 | 1 | 4 | 3 | 5 | 5 | 6 | 6 | 7 | 3 | 7 | 3 | 7 | 1 | 7 | 1 | 355 | 1 |
| 4 | 1 | 5 | 2 | 6 | 4 | 7 | 3 | 8 | 3 | 8 | 0 | 8 | 1 | 8 | 0 | 365 | 1 |
| 5 | 0 | 6 | 3 | 7 | 3 | 8 | 6 | 9 | 5 | 9 | 1 | 9 | 0 | 9 | 0 | 381 | 1 |
| 6 | 1 | 7 | 3 | 8 | 6 | 9 | 6 | 230 | 4 | 250 | 0 | 270 | 0 | 290 | 0 | 521 | 1 |
| 147 | 1 | 168 | 2 | 189 | 6 | 210 | 8 | | | | | | | | | | |

FIFTH DAY, JULY 9, 1872.

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 62 | 1 | 82 | 0 | 101 | 7 | 120 | 3 | 139 | 8 | 158 | 2 | 177 | 6 | 196 | 1 | 215 | 0 |
| 3 | 0 | 3 | 1 | 2 | 5 | 1 | 3 | 140 | 7 | 9 | 8 | 8 | 3 | 7 | 0 | 6 | 1 |
| 4 | 0 | 4 | 0 | 3 | 2 | 2 | 4 | 1 | 5 | 160 | 6 | 9 | 6 | 8 | 0 | 7 | 0 |
| 5 | 2 | 5 | 0 | 4 | 3 | 3 | 5 | 2 | 8 | 1 | 9 | 180 | 5 | 9 | 0 | 8 | 1 |
| 6 | 0 | 6 | 2 | 5 | 4 | 4 | 1 | 3 | 8 | 2 | 7 | 1 | 3 | 200 | 1 | 9 | 0 |
| 7 | 1 | 7 | 0 | 6 | 0 | 5 | 4 | 4 | 11 | 3 | 3 | 2 | 5 | 1 | 0 | 220 | 1 |
| 8 | 1 | 8 | 0 | 7 | 1 | 6 | 2 | 5 | 4 | 4 | 4 | 3 | 3 | 2 | 1 | 1 | 0 |
| 9 | 0 | 9 | 0 | 8 | 3 | 7 | 4 | 6 | 8 | 5 | 3 | 4 | 5 | 3 | 2 | 2 | 0 |
| 70 | 0 | 90 | 2 | 9 | 2 | 8 | 4 | 7 | 6 | 6 | 3 | 5 | 3 | 4 | 2 | 3 | 0 |
| 1 | 0 | 1 | 1 | 110 | 3 | 9 | 1 | 8 | 4 | 7 | 3 | 6 | 4 | 5 | 0 | 4 | 0 |
| 2 | 1 | 2 | 3 | 1 | 2 | 130 | 6 | 9 | 3 | 8 | 4 | 7 | 4 | 6 | 0 | 5 | 1 |
| 3 | 1 | 3 | 3 | 2 | 2 | 1 | 6 | 150 | 5 | 9 | 2 | 8 | 3 | 7 | 1 | 237 | 1 |
| 4 | 1 | 4 | 0 | 3 | 0 | 2 | 5 | 1 | 4 | 170 | 7 | 9 | 2 | 8 | 2 | 247 | 1 |
| 5 | 0 | 5 | 3 | 4 | 3 | 3 | 4 | 2 | 5 | 1 | 6 | 190 | 2 | 9 | 2 | 249 | 1 |
| 6 | 1 | 6 | 2 | 5 | 4 | 4 | 7 | 3 | 8 | 2 | 5 | 1 | 1 | 210 | 2 | 256 | 1 |
| 7 | 2 | 7 | 2 | 6 | 6 | 5 | 7 | 4 | 4 | 3 | 8 | 2 | 4 | 1 | 2 | 259 | 1 |
| 8 | 2 | 8 | 0 | 7 | 4 | 6 | 8 | 5 | 7 | 4 | 6 | 3 | 3 | 2 | 3 | 270 | 1 |
| 9 | 1 | 9 | 0 | 8 | 4 | 7 | 6 | 6 | 10 | 5 | 3 | 4 | 1 | 3 | 0 | 285 | 1 |
| 80 | 2 | 100 | 3 | 119 | 1 | 138 | 9 | 157 | 5 | 176 | 3 | 195 | 1 | 211 | 0 | 310 | 1 |
| 81 | 0 | | | | | | | | | | | | | | | | |

*Details of the experiments*—Continued.

SIXTH DAY, JULY 10, 1872.

| Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 66 | 1 | 117 | 0 | 137 | 2 | 157 | 5 | 177 | 4 | 197 | 3 | 217 | 1 | 237 | 1 | 257 | 0 |
| 72 | 1 | 8 | 1 | 8 | 0 | 8 | 6 | 8 | 3 | 8 | 3 | 8 | 3 | 8 | 1 | 8 | 0 |
| 75 | 1 | 9 | 1 | 9 | 5 | 9 | 7 | 9 | 7 | 9 | 1 | 9 | 2 | 9 | 2 | 9 | 1 |
| 87 | 2 | 120 | 1 | 140 | 5 | 160 | 7 | 180 | 3 | 200 | 5 | 220 | 3 | 240 | 0 | 260 | 1 |
| 88 | 1 | 1 | 1 | 1 | 3 | 1 | 7 | 1 | 4 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 |
| 101 | 2 | 2 | 3 | 2 | 6 | 2 | 3 | 2 | 11 | 2 | 8 | 2 | 1 | 2 | 1 | 2 | 0 |
| 2 | 0 | 3 | 2 | 3 | 3 | 3 | 10 | 3 | 9 | 3 | 2 | 3 | 1 | 3 | 0 | 3 | 0 |
| 3 | 0 | 4 | 2 | 4 | 4 | 4 | 6 | 4 | 7 | 4 | 4 | 4 | 1 | 4 | 3 | 4 | 1 |
| 4 | 1 | 5 | 1 | 5 | 1 | 5 | 12 | 5 | 6 | 5 | 0 | 5 | 2 | 5 | 1 | 272 | 1 |
| 5 | 1 | 6 | 0 | 6 | 6 | 6 | 2 | 6 | 8 | 6 | 2 | 6 | 1 | 6 | 1 | 277 | 1 |
| 6 | 1 | 7 | 0 | 7 | 8 | 7 | 4 | 7 | 9 | 7 | 1 | 7 | 0 | 7 | 0 | 280 | 1 |
| 7 | 1 | 8 | 1 | 8 | 3 | 8 | 5 | 8 | 2 | 8 | 2 | 8 | 1 | 8 | 0 | 285 | 1 |
| 8 | 1 | 9 | 2 | 9 | 4 | 9 | 6 | 9 | 7 | 9 | 1 | 9 | 3 | 9 | 0 | 287 | 2 |
| 9 | 2 | 130 | 1 | 150 | 5 | 170 | 9 | 190 | 7 | 210 | 4 | 230 | 1 | 250 | 0 | 290 | 1 |
| 110 | 0 | 1 | 4 | 1 | 4 | 1 | 5 | 1 | 6 | 1 | 3 | 1 | 0 | 1 | 0 | 316 | 1 |
| 1 | 1 | 2 | 2 | 2 | 7 | 2 | 9 | 2 | 7 | 2 | 3 | 2 | 0 | 2 | 0 | 327 | 1 |
| 2 | 2 | 3 | 0 | 3 | 4 | 3 | 5 | 3 | 5 | 3 | 1 | 3 | 1 | 3 | 0 | 367 | 1 |
| 3 | 2 | 4 | 5 | 4 | 7 | 4 | 5 | 4 | 6 | 4 | 4 | 4 | 0 | 4 | 0 | 376 | 1 |
| 4 | 0 | 5 | 4 | 5 | 4 | 5 | 5 | 5 | 2 | 5 | 3 | 5 | 0 | 5 | 0 | 392 | 1 |
| 5 | 1 | 136 | 1 | 156 | 5 | 176 | 7 | 196 | 7 | 216 | 3 | 236 | 0 | 256 | 0 | 411 | 1 |
| 116 | 3 | | | | | | | | | | | | | | | | |

SEVENTH DAY, JULY 15, 1872.

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 65 | 1 | 107 | 0 | 129 | 2 | 151 | 5 | 173 | 6 | 195 | 4 | 217 | 3 | 238 | 1 | 269 | 0 |
| 67 | 1 | 8 | 1 | 130 | 6 | 2 | 4 | 4 | 3 | 6 | 4 | 8 | 5 | 9 | 0 | 260 | 0 |
| 76 | 1 | 9 | 2 | 1 | 1 | 3 | 6 | 5 | 0 | 7 | 7 | 9 | 4 | 240 | 1 | 1 | 1 |
| 82 | 1 | 110 | 1 | 2 | 2 | 4 | 5 | 6 | 5 | 8 | 4 | 220 | 1 | 1 | 1 | 2 | 0 |
| 89 | 1 | 1 | 0 | 3 | 2 | 5 | 2 | 7 | 4 | 9 | 6 | 1 | 4 | 2 | 0 | 3 | 1 |
| 90 | 1 | 2 | 1 | 4 | 1 | 6 | 5 | 8 | 2 | 200 | 2 | 2 | 2 | 3 | 2 | 4 | 0 |
| 1 | 0 | 3 | 0 | 5 | 0 | 7 | 4 | 9 | 6 | 1 | 4 | 3 | 4 | 4 | 1 | 5 | 1 |
| 2 | 0 | 4 | 4 | 6 | 1 | 8 | 5 | 180 | 6 | 2 | 1 | 4 | 3 | 5 | 2 | 6 | 0 |
| 3 | 0 | 5 | 3 | 7 | 1 | 9 | 2 | 1 | 9 | 3 | 5 | 5 | 1 | 6 | 3 | 7 | 0 |
| 4 | 0 | 6 | 2 | 8 | 2 | 160 | 3 | 2 | 13 | 4 | 5 | 6 | 5 | 7 | 2 | 8 | 1 |
| 5 | 0 | 7 | 3 | 9 | 2 | 1 | 4 | 3 | 6 | 5 | 2 | 7 | 3 | 8 | 2 | 278 | 1 |
| 6 | 1 | 8 | 0 | 140 | 1 | 2 | 5 | 4 | 8 | 6 | 4 | 8 | 4 | 9 | 0 | 282 | 1 |
| 7 | 0 | 9 | 0 | 1 | 1 | 3 | 4 | 5 | 7 | 7 | 7 | 9 | 4 | 250 | 2 | 301 | 2 |
| 8 | 0 | 120 | 0 | 2 | 2 | 4 | 2 | 6 | 6 | 8 | 4 | 230 | 1 | 1 | 1 | 314 | 1 |
| 9 | 0 | 1 | 1 | 3 | 3 | 5 | 7 | 7 | 7 | 9 | 6 | 1 | 5 | 2 | 1 | 336 | 1 |
| 100 | 1 | 2 | 0 | 4 | 2 | 6 | 4 | 8 | 4 | 210 | 4 | 2 | 1 | 3 | 0 | 357 | 1 |
| 1 | 0 | 3 | 0 | 5 | 3 | 7 | 14 | 9 | 5 | 1 | 5 | 3 | 3 | 4 | 0 | 273 | 1 |
| 2 | 2 | 4 | 0 | 6 | 2 | 8 | 4 | 190 | 4 | 2 | 4 | 4 | 2 | 5 | 1 | 376 | 1 |
| 3 | 0 | 5 | 0 | 7 | 7 | 9 | 2 | 1 | 7 | 3 | 8 | 5 | 2 | 6 | 0 | 386 | 1 |
| 4 | 1 | 6 | 1 | 8 | 4 | 170 | 7 | 2 | 1 | 4 | 2 | 6 | 1 | 7 | 1 | 459 | 1 |
| 5 | 0 | 7 | 2 | 9 | 2 | 1 | 3 | 3 | 7 | 5 | 5 | 237 | 3 | 258 | 0 | 687 | 1 |
| 106 | 1 | 128 | 1 | 150 | 1 | 172 | 5 | 194 | 5 | 216 | 0 | | | | | | |

*Details of the experiments*—Continued.

EIGHTH DAY, JULY 16, 1872.

| Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 61 | 1 | 133 | 0 | 151 | 2 | 169 | 5 | 187 | 9 | 204 | 9 | 221 | 5 | 238 | 1 | 255 | 1 |
| 85 | 1 | 4 | 0 | 2 | 2 | 170 | 7 | 8 | 10 | 5 | 10 | 2 | 7 | 9 | 1 | 6 | 0 |
| 105 | 1 | 5 | 0 | 3 | 1 | 1 | 3 | 9 | 3 | 6 | 3 | 3 | 2 | 240 | 0 | 7 | 1 |
| 111 | 1 | 6 | 0 | 4 | 4 | 2 | 3 | 190 | 11 | 7 | 8 | 4 | 1 | 1 | 2 | 8 | 0 |
| 119 | 1 | 7 | 2 | 5 | 5 | 3 | 5 | 1 | 6 | 8 | 5 | 5 | 4 | 2 | 1 | 9 | 0 |
| 120 | 0 | 8 | 2 | 6 | 3 | 4 | 7 | 2 | 8 | 9 | 5 | 6 | 1 | 3 | 1 | 260 | 1 |
| 1 | 0 | 9 | 1 | 7 | 2 | 5 | 4 | 3 | 11 | 210 | 4 | 7 | 2 | 4 | 1 | 1 | 0 |
| 2 | 1 | 140 | 0 | 8 | 4 | 6 | 4 | 4 | 8 | 1 | 3 | 8 | 3 | 5 | 0 | 2 | 1 |
| 3 | 1 | 1 | 0 | 9 | 1 | 7 | 8 | 5 | 8 | 2 | 10 | 9 | 5 | 6 | 0 | 3 | 0 |
| 4 | 0 | 2 | 0 | 160 | 3 | 8 | 3 | 6 | 8 | 3 | 7 | 230 | 4 | 7 | 1 | 4 | 1 |
| 5 | 0 | 3 | 3 | 1 | 2 | 9 | 5 | 7 | 7 | 4 | 9 | 1 | 2 | 8 | 0 | 5 | 1 |
| 6 | 1 | 4 | 1 | 2 | 2 | 180 | 6 | 8 | 8 | 5 | 3 | 2 | 3 | 9 | 0 | 274 | 1 |
| 7 | 0 | 5 | 0 | 3 | 4 | 1 | 9 | 9 | 8 | 6 | 3 | 3 | 1 | 250 | 0 | 288 | 2 |
| 8 | 0 | 6 | 4 | 4 | 0 | 2 | 5 | 200 | 6 | 7 | 6 | 4 | 1 | 1 | 1 | 312 | 1 |
| 9 | 0 | 7 | 2 | 5 | 3 | 3 | 6 | 1 | 4 | 8 | 5 | 5 | 3 | 2 | 0 | 318 | 1 |
| 130 | 0 | 8 | 2 | 6 | 4 | 4 | 10 | 2 | 13 | 9 | 2 | 6 | 0 | 3 | 2 | 335 | 1 |
| 1 | 1 | 9 | 2 | 7 | 4 | 5 | 4 | 203 | 7 | 220 | 10 | 237 | 1 | 254 | 0 | 360 | 1 |
| 132 | 1 | 150 | 1 | 168 | 3 | 186 | 11 | | | | | | | | | | |

NINTH DAY, JULY 17, 1872.

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 71 | 1 | 136 | 1 | 154 | 4 | 172 | 2 | 189 | 6 | 206 | 9 | 223 | 2 | 240 | 1 | 257 | 0 |
| 77 | 1 | 7 | 0 | 5 | 3 | 3 | 6 | 190 | 9 | 7 | 3 | 4 | 4 | 1 | 0 | 8 | 1 |
| 88 | 1 | 8 | 1 | 6 | 1 | 4 | 5 | 1 | 6 | 8 | 6 | 5 | 5 | 2 | 0 | 9 | 0 |
| 106 | 1 | 9 | 2 | 7 | 3 | 5 | 8 | 2 | 5 | 9 | 8 | 6 | 0 | 3 | 0 | 260 | 0 |
| 114 | 1 | 140 | 1 | 8 | 3 | 6 | 6 | 3 | 8 | 210 | 5 | 7 | 5 | 4 | 2 | 1 | 1 |
| 115 | 1 | 1 | 1 | 9 | 2 | 7 | 6 | 4 | 6 | 1 | 8 | 8 | 1 | 5 | 0 | 2 | 0 |
| 124 | 1 | 2 | 1 | 160 | 1 | 8 | 4 | 5 | 10 | 2 | 6 | 9 | 4 | 6 | 4 | 3 | 0 |
| 5 | 0 | 3 | 3 | 1 | 2 | 9 | 7 | 6 | 7 | 3 | 7 | 230 | 2 | 7 | 1 | 4 | 1 |
| 6 | 0 | 4 | 0 | 2 | 2 | 180 | 2 | 7 | 6 | 4 | 5 | 1 | 0 | 8 | 0 | 276 | 1 |
| 7 | 1 | 5 | 1 | 3 | 1 | 1 | 8 | 8 | 14 | 5 | 6 | 2 | 3 | 9 | 1 | 281 | 2 |
| 8 | 0 | 6 | 3 | 4 | 5 | 2 | 7 | 9 | 7 | 6 | 6 | 3 | 4 | 250 | 2 | 286 | 1 |
| 9 | 2 | 7 | 2 | 5 | 4 | 3 | 5 | 200 | 8 | 7 | 4 | 4 | 2 | 1 | 0 | 301 | 2 |
| 130 | 0 | 8 | 0 | 6 | 5 | 4 | 8 | 1 | 10 | 8 | 7 | 5 | 1 | 2 | 0 | 302 | 1 |
| 1 | 0 | 9 | 2 | 7 | 2 | 5 | 5 | 2 | 6 | 9 | 3 | 6 | 2 | 3 | 1 | 307 | 1 |
| 2 | 2 | 150 | 2 | 8 | 2 | 6 | 8 | 3 | 3 | 220 | 8 | 7 | 2 | 4 | 1 | 347 | 1 |
| 3 | 0 | 1 | 2 | 9 | 5 | 7 | 6 | 4 | 8 | 1 | 3 | 8 | 3 | 5 | 1 | 368 | 1 |
| 4 | 2 | 2 | 1 | 170 | 8 | 188 | 11 | 205 | 6 | 222 | 5 | 239 | 4 | 256 | 0 | 505 | 1 |
| 135 | 1 | 153 | 2 | 171 | 2 | | | | | | | | | | | | |

*Details of the experiments*—Continued.

TENTH DAY, JULY 18, 1872.

| Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 81 | 1 | 165 | 0 | 183 | 5 | 200 | 5 | 217 | 7 | 234 | 4 | 251 | 6 | 268 | 0 | 285 | 1 |
| 122 | 1 | 6 | 2 | 4 | 1 | 1 | 4 | 8 | 10 | 5 | 2 | 2 | 2 | 9 | 0 | 6 | 0 |
| 130 | 1 | 7 | 2 | 5 | 6 | 2 | 5 | 9 | 9 | 6 | 9 | 3 | 4 | 270 | 0 | 7 | 0 |
| 150 | 1 | 8 | 0 | 6 | 4 | 3 | 6 | 220 | 10 | 7 | 6 | 4 | 2 | 1 | 0 | 8 | 1 |
| 1 | 1 | 9 | 1 | 7 | 5 | 4 | 5 | 1 | 9 | 8 | 4 | 5 | 5 | 2 | 2 | 9 | 0 |
| 2 | 0 | 170 | 2 | 8 | 4 | 5 | 7 | 2 | 5 | 9 | 9 | 6 | 2 | 3 | 0 | 290 | 0 |
| 3 | 0 | 1 | 3 | 9 | 5 | 6 | 7 | 3 | 4 | 240 | 4 | 7 | 1 | 4 | 1 | 1 | 0 |
| 4 | 0 | 2 | 3 | 190 | 3 | 7 | 10 | 4 | 11 | 1 | 4 | 8 | 2 | 5 | 1 | 2 | 0 |
| 5 | 0 | 3 | 1 | 1 | 4 | 8 | 13 | 5 | 4 | 2 | 1 | 9 | 1 | 6 | 0 | 3 | 0 |
| 6 | 1 | 4 | 1 | 2 | 3 | 9 | 6 | 6 | 9 | 3 | 6 | 260 | 2 | 7 | 0 | 4 | 1 |
| 7 | 1 | 5 | 2 | 3 | 7 | 210 | 11 | 7 | 8 | 4 | 7 | 1 | 2 | 8 | 0 | 5 | 0 |
| 8 | 0 | 6 | 1 | 4 | 1 | 1 | 8 | 8 | 10 | 5 | 0 | 2 | 2 | 9 | 0 | 6 | 0 |
| 9 | 1 | 7 | 1 | 5 | 9 | 2 | 11 | 9 | 5 | 6 | 2 | 3 | 0 | 280 | 0 | 7 | 0 |
| 160 | 0 | 8 | 5 | 6 | 7 | 3 | 5 | 230 | 8 | 7 | 3 | 4 | 1 | 1 | 1 | 8 | 0 |
| 1 | 1 | 9 | 2 | 7 | 6 | 4 | 8 | 1 | 9 | 8 | 2 | 5 | 3 | 2 | 0 | 9 | 1 |
| 2 | 2 | 180 | 2 | 8 | 2 | 5 | 10 | 2 | 7 | 9 | 2 | 6 | 0 | 3 | 0 | 302 | 1 |
| 3 | 1 | 1 | 4 | 199 | 8 | 216 | 4 | 233 | 1 | 250 | 3 | 267 | 1 | 284 | 0 | 446 | 1 |
| 164 | 3 | 182 | 5 | | | | | | | | | | | | | | |

ELEVENTH DAY, JULY 19, 1872.

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 68 | 1 | 158 | 1 | 178 | 1 | 198 | 7 | 218 | 11 | 238 | 8 | 258 | 1 | 278 | 2 | 298 | 0 |
| 114 | 1 | 9 | 3 | 9 | 0 | 9 | 8 | 9 | 5 | 9 | 5 | 9 | 1 | 9 | 0 | 9 | 0 |
| 135 | 1 | 160 | 1 | 180 | 3 | 200 | 7 | 220 | 10 | 240 | 2 | 260 | 3 | 280 | 0 | 300 | 1 |
| 141 | 2 | 1 | 1 | 1 | 1 | 1 | 9 | 1 | 7 | 1 | 7 | 1 | 1 | 1 | 1 | 1 | 0 |
| 2 | 2 | 2 | 3 | 2 | 4 | 2 | 5 | 2 | 3 | 2 | 5 | 2 | 2 | 2 | 0 | 2 | 0 |
| 3 | 0 | 3 | 1 | 3 | 2 | 3 | 4 | 3 | 3 | 3 | 3 | 3 | 0 | 3 | 0 | 3 | 1 |
| 4 | 1 | 4 | 0 | 4 | 2 | 4 | 7 | 4 | 9 | 4 | 1 | 4 | 1 | 4 | 0 | 4 | 0 |
| 5 | 1 | 5 | 1 | 5 | 2 | 5 | 4 | 5 | 11 | 5 | 6 | 5 | 1 | 5 | 0 | 5 | 1 |
| 6 | 1 | 6 | 3 | 6 | 3 | 6 | 5 | 6 | 2 | 6 | 2 | 6 | 2 | 6 | 0 | 6 | 0 |
| 7 | 0 | 7 | 0 | 7 | 6 | 7 | 9 | 7 | 8 | 7 | 3 | 7 | 0 | 7 | 1 | 7 | 1 |
| 8 | 0 | 8 | 2 | 8 | 3 | 8 | 6 | 8 | 4 | 8 | 3 | 8 | 1 | 8 | 0 | 8 | 0 |
| 9 | 1 | 9 | 3 | 9 | 5 | 9 | 7 | 9 | 2 | 9 | 6 | 9 | 0 | 9 | 0 | 9 | 0 |
| 150 | 0 | 170 | 0 | 190 | 3 | 210 | 12 | 230 | 5 | 250 | 4 | 270 | 2 | 290 | 0 | 310 | 0 |
| 1 | 1 | 1 | 2 | 1 | 5 | 1 | 12 | 1 | 3 | 1 | 5 | 1 | 1 | 1 | 0 | 1 | 0 |
| 2 | 0 | 2 | 0 | 2 | 12 | 2 | 5 | 2 | 7 | 2 | 2 | 2 | 0 | 2 | 3 | 2 | 3 |
| 3 | 0 | 3 | 0 | 3 | 9 | 3 | 5 | 3 | 4 | 3 | 2 | 3 | 1 | 3 | 1 | 360 | 1 |
| 4 | 2 | 4 | 2 | 4 | 10 | 4 | 7 | 4 | 5 | 4 | 2 | 4 | 3 | 4 | 0 | 379 | 1 |
| 5 | 2 | 5 | 2 | 5 | 10 | 5 | 5 | 5 | 4 | 5 | 2 | 5 | 1 | 5 | 0 | 400 | 1 |
| 6 | 2 | 6 | 3 | 6 | 5 | 6 | 7 | 6 | 4 | 6 | 0 | 6 | 0 | 6 | 0 | 437 | 1 |
| 157 | 0 | 177 | 3 | 197 | 4 | 217 | 5 | 237 | 3 | 257 | 4 | 277 | 1 | 297 | 0 | 491 | 1 |

*Details of the experiments*—Continued.

TWELFTH DAY, JULY 20, 1872.

| Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 95 | 1 | 175 | 1 | 193 | 2 | 211 | 1 | 229 | 6 | 247 | 3 | 265 | 5 | 282 | 0 | 299 | 0 |
| 109 | 1 | 6 | 0 | 4 | 2 | 2 | 2 | 230 | 8 | 8 | 1 | 6 | 3 | 3 | 2 | 300 | 1 |
| 126 | 1 | 7 | 0 | 5 | 0 | 3 | 6 | 1 | 4 | 9 | 2 | 7 | 5 | 4 | 3 | 1 | 0 |
| 141 | 1 | 8 | 0 | 6 | 5 | 4 | 5 | 2 | 3 | 250 | 2 | 8 | 1 | 5 | 0 | 2 | 0 |
| 157 | 1 | 9 | 1 | 7 | 0 | 5 | 5 | 3 | 9 | 1 | 7 | 9 | 4 | 6 | 1 | 3 | 0 |
| 162 | 1 | 180 | 0 | 8 | 4 | 6 | 7 | 4 | 6 | 2 | 3 | 270 | 4 | 7 | 0 | 4 | 1 |
| 3 | 0 | 1 | 1 | 9 | 1 | 7 | 5 | 5 | 6 | 3 | 3 | 1 | 2 | 8 | 0 | 5 | 1 |
| 4 | 1 | 2 | 1 | 200 | 3 | 8 | 8 | 6 | 5 | 4 | 3 | 2 | 1 | 9 | 2 | 314 | 1 |
| 5 | 0 | 3 | 0 | 1 | 2 | 9 | 6 | 7 | 4 | 5 | 5 | 3 | 1 | 290 | 0 | 316 | 1 |
| 6 | C | 4 | 0 | 2 | 2 | 220 | 12 | 8 | 4 | 6 | 6 | 4 | 3 | 1 | 0 | 318 | 1 |
| 7 | 0 | 5 | 0 | 3 | 1 | 1 | 8 | 9 | 6 | 7 | 5 | 5 | 1 | 2 | 1 | 322 | 1 |
| 8 | 0 | 6 | 0 | 4 | 1 | 2 | 11 | 240 | 11 | 8 | 1 | 6 | 1 | 3 | 0 | 329 | 1 |
| 9 | 0 | 7 | 1 | 5 | 2 | 3 | 4 | 1 | 4 | 9 | 3 | 7 | 1 | 4 | 0 | 354 | 1 |
| 170 | 1 | 8 | 0 | 6 | 4 | 4 | 4 | 2 | 7 | 260 | 2 | 8 | 0 | 5 | 0 | 365 | 1 |
| 1 | 0 | 9 | 0 | 7 | 5 | 5 | 6 | 3 | 6 | 1 | 4 | 9 | 1 | 6 | 1 | 374 | 1 |
| 2 | 2 | 190 | 0 | 8 | 3 | 6 | 5 | 4 | 5 | 2 | 3 | 280 | 0 | 7 | 1 | 390 | 1 |
| 3 | 1 | 1 | 3 | 9 | 4 | 7 | 5 | 5 | 5 | 3 | 1 | 281 | 3 | 298 | 1 | 391 | 1 |
| 174 | 0 | 192 | 0 | 210 | 2 | 228 | 13 | 246 | 6 | 264 | 1 | | | | | | |

THIRTEENTH DAY, JULY 22, 1872.

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 133 | 1 | 166 | 0 | 185 | 0 | 204 | 0 | 223 | 8 | 242 | 8 | 261 | 14 | 280 | 3 | 299 | 0 |
| 140 | 1 | 7 | 0 | 6 | 0 | 5 | 1 | 4 | 5 | 3 | 11 | 2 | 8 | 1 | 0 | 300 | 0 |
| 148 | 1 | 8 | 0 | 7 | 0 | 6 | 3 | 5 | 9 | 4 | 8 | 3 | 4 | 2 | 3 | 1 | 0 |
| 9 | 1 | 9 | 0 | 8 | 1 | 7 | 3 | 6 | 5 | 5 | 9 | 4 | 7 | 3 | 6 | 2 | 0 |
| 150 | 0 | 170 | 0 | 9 | 0 | 8 | 4 | 7 | 5 | 6 | 7 | 5 | 2 | 4 | 2 | 3 | 0 |
| 1 | 0 | 1 | 0 | 190 | 0 | 9 | 2 | 8 | 9 | 7 | 9 | 6 | 6 | 5 | 1 | 4 | 1 |
| 2 | 0 | 2 | 0 | 1 | 0 | 210 | 2 | 9 | 4 | 8 | 7 | 7 | 4 | 6 | 0 | 5 | 0 |
| 3 | 0 | 3 | 0 | 2 | 0 | 1 | 6 | 230 | 8 | 9 | 9 | 8 | 5 | 7 | 4 | 6 | 1 |
| 4 | 0 | 4 | 0 | 3 | 0 | 2 | 4 | 1 | 13 | 250 | 5 | 9 | 6 | 8 | 0 | 7 | 0 |
| 5 | 0 | 5 | 0 | 4 | 1 | 3 | 1 | 2 | 7 | 1 | 9 | 270 | 5 | 9 | 0 | 8 | 0 |
| 6 | 0 | 6 | 0 | 5 | 2 | 4 | 3 | 3 | 6 | 2 | 8 | 1 | 6 | 290 | 1 | 9 | 0 |
| 7 | 1 | 7 | 1 | 6 | 0 | 5 | 2 | 4 | 13 | 3 | 8 | 2 | 3 | 1 | 1 | 310 | 1 |
| 8 | 1 | 8 | 0 | 7 | 0 | 6 | 3 | 5 | 8 | 4 | 5 | 3 | 2 | 2 | 0 | 1 | 1 |
| 9 | 0 | 9 | 0 | 8 | 2 | 7 | 2 | 6 | 6 | 5 | 13 | 4 | 5 | 3 | 1 | 2 | 1 |
| 160 | 0 | 180 | 0 | 9 | 0 | 8 | 4 | 7 | 3 | 6 | 2 | 5 | 5 | 4 | 1 | 3 | 0 |
| 1 | 0 | 1 | 0 | 200 | 1 | 9 | 4 | 8 | 10 | 7 | 7 | 6 | 3 | 5 | 2 | 4 | 0 |
| 2 | 0 | 2 | 0 | 1 | 0 | 220 | 5 | 9 | 5 | 8 | 4 | 7 | 2 | 6 | 3 | 5 | 0 |
| 3 | 0 | 3 | 0 | 2 | 0 | 1 | 10 | 240 | 5 | 9 | 7 | 8 | 2 | 7 | 1 | 6 | 1 |
| 4 | 1 | 184 | 1 | 203 | 2 | 222 | 5 | 241 | 7 | 260 | 5 | 279 | 3 | 298 | 2 | 373 | 1 |
| 165 | 0 | | | | | | | | | | | | | | | | |

*Details of the experiments*—Continued.

FOURTEENTH DAY, JULY 23, 1872.

| Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 63 | 1 | 185 | 0 | 203 | 4 | 221 | 6 | 239 | 13 | 256 | 12 | 273 | 2 | 290 | 2 | 307 | 0 |
| 105 | 1 | 6 | 0 | 4 | 2 | 2 | 9 | 240 | 6 | 7 | 1 | 4 | 0 | 1 | 0 | 8 | |
| 119 | 1 | 7 | 4 | 5 | 3 | 3 | 5 | 1 | 10 | 8 | 6 | 5 | 3 | 2 | 0 | 9 | |
| 132 | 1 | 8 | 2 | 6 | 5 | 4 | 10 | 2 | 9 | 9 | 2 | 6 | 0 | 3 | 0 | 310 | 0 |
| 157 | 1 | 9 | 2 | 7 | 2 | 5 | 9 | 3 | 11 | 260 | 6 | 7 | 0 | 4 | 0 | 1 | |
| 158 | 1 | 190 | 0 | 8 | 1 | 6 | 6 | 4 | 8 | 1 | 6 | 8 | 2 | 5 | 0 | 2 | |
| 166 | 1 | 1 | 3 | 9 | 8 | 7 | 6 | 5 | 9 | 2 | 2 | 9 | 1 | 6 | 0 | 3 | |
| 174 | 1 | 2 | 1 | 210 | 5 | 8 | 11 | 6 | 11 | 3 | 5 | 280 | 1 | 7 | 1 | 4 | 0 |
| 5 | 0 | 3 | 1 | 1 | 8 | 9 | 14 | 7 | 5 | 4 | 3 | 1 | 1 | 8 | 0 | 5 | 0 |
| 6 | 0 | 4 | 0 | 2 | 1 | 230 | 10 | 8 | 8 | 5 | 1 | 2 | 1 | 9 | 0 | 6 | 0 |
| 7 | 0 | 5 | 2 | 3 | 5 | 1 | 11 | 9 | 3 | 6 | 4 | 3 | 1 | 300 | 0 | 7 | 2 |
| 8 | 0 | 6 | 4 | 4 | 4 | 2 | 5 | 250 | 5 | 7 | 2 | 4 | 0 | 1 | 0 | 8 | 0 |
| 9 | 1 | 7 | 3 | 5 | 3 | 3 | 8 | 1 | 7 | 8 | 1 | 5 | 0 | 2 | 0 | 9 | 1 |
| 180 | 1 | 8 | 2 | 6 | 2 | 4 | 6 | 2 | 9 | 9 | 0 | 6 | 1 | 3 | 0 | 359 | 1 |
| 1 | 1 | 9 | 1 | 7 | 4 | 5 | 9 | 3 | 9 | 270 | 1 | 7 | 0 | 4 | 1 | 470 | 1 |
| 2 | 0 | 200 | 4 | 8 | 7 | 6 | 8 | 4 | 8 | 1 | 3 | 8 | 0 | 5 | 1 | 693 | 1 |
| 3 | 0 | 1 | 4 | 9 | 3 | 7 | 11 | 255 | 7 | 272 | 4 | 289 | 1 | 306 | 2 | 705 | 1 |
| 184 | 3 | 202 | 1 | 220 | 4 | 238 | 12 | | | | | | | | | | |

FIFTEENTH DAY, JULY 24, 1872.

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 73 | 1 | 177 | 0 | 195 | 2 | 213 | 4 | 231 | 5 | 249 | 4 | 267 | 1 | 285 | 1 | 302 | 1 |
| 105 | 1 | 8 | 0 | 6 | 1 | 4 | 9 | 2 | 11 | 250 | 7 | 8 | 7 | 6 | 0 | 3 | 0 |
| 110 | 1 | 9 | 1 | 7 | 1 | 5 | 8 | 3 | 8 | 1 | 4 | 9 | 1 | 7 | 1 | 4 | 0 |
| 112 | 1 | 180 | 0 | 8 | 3 | 6 | 4 | 4 | 8 | 2 | 6 | 270 | 4 | 8 | 2 | 5 | 0 |
| 140 | 1 | 1 | 0 | 9 | 1 | 7 | 8 | 5 | 9 | 3 | 3 | 1 | 3 | 9 | 1 | 6 | 0 |
| 148 | 1 | 2 | 0 | 200 | 0 | 8 | 7 | 6 | 15 | 4 | 4 | 2 | 4 | 290 | 1 | 7 | 0 |
| 158 | 1 | 3 | 0 | 1 | 1 | 9 | 9 | 7 | 7 | 5 | 7 | 3 | 1 | 1 | 0 | 8 | 0 |
| 166 | 1 | 4 | 1 | 2 | 4 | 220 | 5 | 8 | 12 | 6 | 8 | 4 | 1 | 2 | 1 | 9 | 2 |
| 7 | 0 | 5 | 0 | 3 | 1 | 1 | 5 | 9 | 10 | 7 | 6 | 5 | 2 | 3 | 1 | 310 | 1 |
| 8 | 1 | 6 | 1 | 4 | 2 | 2 | 10 | 240 | 15 | 8 | 3 | 6 | 1 | 4 | 0 | 1 | 1 |
| 9 | 1 | 7 | 3 | 5 | 2 | 3 | 12 | 1 | 9 | 9 | 1 | 7 | 1 | 5 | 2 | 2 | 0 |
| 170 | 0 | 8 | 0 | 6 | 1 | 4 | 7 | 2 | 8 | 260 | 2 | 8 | 1 | 6 | 1 | 3 | 0 |
| 1 | 0 | 9 | 0 | 7 | 0 | 5 | 6 | 3 | 14 | 1 | 3 | 9 | 3 | 7 | 0 | 4 | 0 |
| 2 | 0 | 190 | 0 | 8 | 5 | 6 | 7 | 4 | 4 | 2 | 8 | 280 | 1 | 8 | 0 | 5 | 1 |
| 3 | 0 | 1 | 0 | 9 | 4 | 7 | 8 | 5 | 4 | 3 | 3 | 1 | 0 | 9 | 0 | 406 | 1 |
| 4 | 2 | 2 | 2 | 210 | 6 | 8 | 11 | 6 | 7 | 4 | 1 | 2 | 1 | 300 | 0 | 443 | 1 |
| 5 | 1 | 3 | 4 | 1 | 5 | 9 | 8 | 7 | 7 | 5 | 1 | 3 | 0 | 301 | 0 | 467 | 2 |
| 176 | 0 | 194 | 1 | 212 | 5 | 230 | 12 | 248 | 8 | 266 | 2 | 284 | 1 | | | | |

*Details of the experiments*—Continued.

SIXTEENTH DAY, JULY 25, 1872.

| Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 67 | 1 | 170 | 2 | 186 | 0 | 202 | 2 | 218 | 6 | 234 | 8 | 250 | 6 | 266 | 4 | 282 | 2 |
| 86 | 1 | 1 | 0 | 7 | 3 | 3 | 4 | 9 | 8 | 5 | 10 | 1 | 10 | 7 | 5 | 3 | 0 |
| 103 | 1 | 2 | 0 | 8 | 3 | 4 | 1 | 220 | 8 | 6 | 8 | 2 | 6 | 8 | 6 | 4 | 2 |
| 114 | 1 | 3 | 0 | 9 | 0 | 5 | 10 | 1 | 5 | 7 | 5 | 3 | 3 | 9 | 3 | 5 | 0 |
| 157 | 1 | 4 | 0 | 190 | 1 | 6 | 3 | 2 | 3 | 8 | 7 | 4 | 5 | 270 | 4 | 6 | 0 |
| 8 | 0 | 5 | 0 | 1 | 0 | 7 | 6 | 3 | 3 | 9 | 7 | 5 | 4 | 1 | 4 | 7 | 1 |
| 9 | 0 | 6 | 3 | 2 | 2 | 8 | 4 | 4 | 6 | 240 | 6 | 6 | 10 | 2 | 1 | 8 | 0 |
| 160 | 0 | 7 | 0 | 3 | 4 | 9 | 3 | 5 | 10 | 1 | 11 | 7 | 7 | 3 | 3 | 9 | 0 |
| 1 | 1 | 8 | 1 | 4 | 1 | 210 | 1 | 6 | 7 | 2 | 11 | 8 | 4 | 4 | 2 | 290 | 0 |
| 2 | 1 | 9 | 1 | 5 | 0 | 1 | 7 | 7 | 8 | 3 | 12 | 9 | 3 | 5 | 0 | 1 | 1 |
| 3 | 0 | 180 | 2 | 6 | 2 | 2 | 5 | 8 | 9 | 4 | 9 | 260 | 0 | 6 | 0 | 303 | 1 |
| 4 | 0 | 1 | 1 | 7 | 1 | 3 | 3 | 9 | 12 | 5 | 7 | 1 | 2 | 7 | 0 | 312 | 1 |
| 5 | 0 | 2 | 2 | 8 | 3 | 4 | 3 | 230 | 15 | 6 | 6 | 2 | 3 | 8 | 1 | 313 | 1 |
| 6 | 0 | 3 | 2 | 9 | 4 | 5 | 2 | 1 | 13 | 7 | 7 | 3 | 2 | 9 | 1 | 333 | 1 |
| 7 | 0 | 4 | 1 | 200 | 5 | 6 | 4 | 2 | 6 | 8 | 7 | 4 | 0 | 280 | 4 | 357 | 1 |
| 8 | 0 | 185 | 3 | 201 | 6 | 217 | 5 | 233 | 8 | 249 | 8 | 265 | 2 | 281 | 2 | 784 | 1 |
| 169 | 0 | | | | | | | | | | | | | | | | |

SEVENTEENTH DAY, JULY 26, 1872.

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 76 | 1 | 195 | 0 | 216 | 1 | 237 | 5 | 258 | 9 | 279 | 10 | 300 | 4 | 321 | 1 | 342 | 1 |
| 104 | 1 | 6 | 2 | 7 | 0 | 8 | 2 | 9 | 7 | 280 | 4 | 1 | 0 | 2 | 0 | 3 | 0 |
| 128 | 1 | 7 | 0 | 8 | 1 | 9 | 5 | 260 | 11 | 1 | 7 | 2 | 1 | 3 | 1 | 4 | 1 |
| 147 | 1 | 8 | 0 | 9 | 2 | 240 | 7 | 1 | 9 | 2 | 6 | 3 | 1 | 4 | 1 | 5 | 3 |
| 162 | 1 | 9 | 0 | 220 | 3 | 1 | 2 | 2 | 8 | 3 | 7 | 4 | 1 | 5 | 1 | 6 | 0 |
| 166 | 1 | 200 | 1 | 1 | 3 | 2 | 4 | 3 | 5 | 4 | 7 | 5 | 1 | 6 | 1 | 7 | 1 |
| 180 | 1 | 1 | 1 | 2 | 0 | 3 | 5 | 4 | 7 | 5 | 3 | 6 | 2 | 7 | 0 | 8 | 2 |
| 1 | 0 | 2 | 0 | 3 | 4 | 4 | 4 | 5 | 8 | 6 | 6 | 7 | 0 | 8 | 0 | 9 | 0 |
| 2 | 0 | 3 | 1 | 4 | 3 | 5 | 9 | 6 | 5 | 7 | 7 | 8 | 2 | 9 | 0 | 350 | 0 |
| 3 | 0 | 4 | 0 | 5 | 2 | 6 | 2 | 7 | 3 | 8 | 3 | 9 | 5 | 330 | 0 | 1 | 0 |
| 4 | 0 | 5 | 0 | 6 | 0 | 7 | 5 | 8 | 7 | 9 | 5 | 310 | 6 | 1 | 0 | 2 | 0 |
| 5 | 0 | 6 | 1 | 7 | 2 | 8 | 4 | 9 | 2 | 290 | 5 | 1 | 1 | 2 | 1 | 3 | 1 |
| 6 | 3 | 7 | 2 | 8 | 1 | 9 | 8 | 270 | 6 | 1 | 6 | 2 | 4 | 3 | 0 | 366 | 1 |
| 7 | 0 | 8 | 5 | 9 | 3 | 250 | 5 | 1 | 5 | 2 | 7 | 3 | 0 | 4 | 0 | 372 | 1 |
| 8 | 0 | 9 | 4 | 230 | 6 | 1 | 7 | 2 | 6 | 3 | 5 | 4 | 1 | 5 | 0 | 380 | 1 |
| 9 | 0 | 210 | 2 | 1 | 2 | 2 | 4 | 3 | 7 | 4 | 5 | 5 | 4 | 6 | 0 | 390 | 1 |
| 190 | 1 | 1 | 2 | 2 | 4 | 3 | 5 | 4 | 5 | 5 | 3 | 6 | 1 | 7 | 1 | 392 | 1 |
| 1 | 0 | 2 | 2 | 3 | 3 | 4 | 7 | 5 | 6 | 6 | 5 | 7 | 2 | 8 | 1 | 394 | 1 |
| 2 | 0 | 3 | 2 | 4 | 3 | 5 | 7 | 6 | 11 | 7 | 1 | 8 | 0 | 9 | 1 | 448 | 1 |
| 3 | 1 | 4 | 2 | 5 | 4 | 6 | 5 | 7 | 2 | 8 | 3 | 9 | 0 | 340 | 0 | 467 | 1 |
| 194 | 0 | 215 | 2 | 236 | 3 | 257 | 7 | 278 | 5 | 299 | 3 | 320 | 2 | 341 | 1 | | |

*Details of the experiments*—Continued.

EIGHTEENTH DAY, JULY 27, 1872.

| Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 184 | 2 | 201 | 3 | 218 | 0 | 235 | 4 | 252 | 16 | 269 | 5 | 286 | 6 | 302 | 2 | 318 | 0 |
| 5 | 0 | 2 | 1 | 9 | 3 | 6 | 10 | 3 | 6 | 270 | 11 | 7 | 4 | 3 | 1 | 9 | 0 |
| 6 | 0 | 3 | 2 | 220 | 2 | 7 | 5 | 4 | 10 | 1 | 10 | 8 | 1 | 4 | 0 | 320 | 0 |
| 7 | 0 | 4 | 2 | 1 | 3 | 8 | 2 | 5 | 11 | 2 | 6 | 9 | 1 | 5 | 1 | 1 | 0 |
| 8 | 1 | 5 | 0 | 2 | 0 | 9 | 5 | 6 | 8 | 3 | 6 | 290 | 1 | 6 | 1 | 2 | 1 |
| 9 | 0 | 6 | 6 | 3 | 4 | 240 | 6 | 7 | 7 | 4 | 5 | 1 | 3 | 7 | 0 | 3 | 0 |
| 190 | 0 | 7 | 1 | 4 | 6 | 1 | 5 | 8 | 7 | 5 | 7 | 2 | 1 | 8 | 0 | 4 | 0 |
| 1 | 0 | 8 | 1 | 5 | 2 | 2 | 3 | 9 | 8 | 6 | 5 | 3 | 1 | 9 | 0 | 5 | 0 |
| 2 | 1 | 9 | 3 | 6 | 0 | 3 | 8 | 260 | 13 | 7 | 5 | 4 | 2 | 310 | 0 | 6 | 0 |
| 3 | 0 | 210 | 0 | 7 | 5 | 4 | 6 | 1 | 9 | 8 | 3 | 5 | 0 | 1 | 0 | 7 | 0 |
| 4 | 0 | 1 | 0 | 8 | 3 | 5 | 5 | 2 | 5 | 9 | 6 | 6 | 0 | 2 | 0 | 8 | 0 |
| 5 | 0 | 2 | 3 | 9 | 8 | 6 | 7 | 3 | 16 | 280 | 3 | 7 | 0 | 3 | 0 | 9 | 0 |
| 6 | 0 | 3 | 3 | 230 | 7 | 7 | 14 | 4 | 11 | 1 | 1 | 8 | 0 | 4 | 0 | 330 | 1 |
| 7 | 1 | 4 | 1 | 1 | 2 | 8 | 8 | 5 | 4 | 2 | 4 | 9 | 2 | 5 | 1 | 341 | 1 |
| 8 | 0 | 5 | 3 | 2 | 10 | 9 | 11 | 6 | 6 | 3 | 5 | 300 | 0 | 6 | 0 | 366 | 1 |
| 9 | 1 | 6 | 4 | 3 | 3 | 250 | 12 | 7 | 8 | 4 | 5 | 301 | 0 | 317 | 0 | 367 | 1 |
| 200 | 0 | 217 | 4 | 234 | 6 | 251 | 3 | 268 | 5 | 285 | 4 | | | | | | |

NINETEENTH DAY, JULY 29, 1872.

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 119 | 1 | 200 | 0 | 217 | 0 | 234 | 5 | 251 | 11 | 267 | 8 | 283 | 2 | 299 | 1 | 315 | 0 |
| 148 | 1 | 1 | 0 | 8 | 1 | 5 | 2 | 2 | 10 | 8 | 6 | 4 | 1 | 300 | 1 | 6 | 0 |
| 152 | 1 | 2 | 0 | 9 | 2 | 6 | 7 | 3 | 13 | 9 | 11 | 5 | 3 | 1 | 2 | 7 | 0 |
| 157 | 1 | 3 | 1 | 220 | 3 | 7 | 7 | 4 | 15 | 270 | 6 | 6 | 5 | 2 | 1 | 8 | 1 |
| 187 | 1 | 4 | 0 | 1 | 3 | 8 | 9 | 5 | 11 | 1 | 10 | 7 | 4 | 3 | 0 | 9 | 0 |
| 8 | 0 | 5 | 1 | 2 | 3 | 9 | 4 | 6 | 12 | 2 | 12 | 8 | 4 | 4 | 0 | 320 | 0 |
| 9 | 0 | 6 | 0 | 3 | 0 | 240 | 11 | 7 | 7 | 3 | 9 | 9 | 5 | 5 | 0 | 1 | 1 |
| 190 | 1 | 7 | 2 | 4 | 1 | 1 | 8 | 8 | 11 | 4 | 10 | 290 | 1 | 6 | 0 | 2 | 0 |
| 1 | 1 | 8 | 0 | 5 | 0 | 2 | 7 | 9 | 6 | 5 | 4 | 1 | 0 | 7 | 0 | 3 | 0 |
| 2 | 0 | 9 | 0 | 6 | 2 | 3 | 8 | 260 | 11 | 6 | 5 | 2 | 1 | 8 | 2 | 4 | 1 |
| 3 | 0 | 210 | 2 | 7 | 7 | 4 | 7 | 1 | 8 | 7 | 5 | 3 | 2 | 9 | 1 | 334 | 1 |
| 4 | 0 | 1 | 0 | 8 | 0 | 5 | 10 | 2 | 11 | 8 | 4 | 4 | 1 | 310 | 1 | 359 | 1 |
| 5 | 0 | 2 | 1 | 9 | 3 | 6 | 11 | 3 | 4 | 9 | 2 | 5 | 1 | 1 | 1 | 366 | 1 |
| 3 | 0 | 3 | 0 | 230 | 3 | 7 | 8 | 4 | 4 | 280 | 7 | 6 | 1 | 2 | 0 | 591 | 1 |
| 7 | 0 | 4 | 1 | 1 | 4 | 8 | 11 | 5 | 4 | 1 | 5 | 7 | 0 | 3 | 0 | 779 | 1 |
| 8 | 1 | 5 | 1 | 2 | 3 | 9 | 13 | 266 | 8 | 282 | 4 | 298 | 1 | 314 | 0 | 851 | 1 |
| 199 | 1 | 216 | 1 | 233 | 6 | 250 | 7 | | | | | | | | | | |

*Details of the experiments*—Continued.

TWENTIETH DAY, JULY 30, 1871.

| Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 130 | 1 | 195 | 0 | 214 | 2 | 233 | 10 | 252 | 12 | 271 | 1 | 290 | 1 | 309 | 1 | 328 | 0 |
| 159 | 1 | 6 | 0 | 5 | 3 | 4 | 4 | 3 | 9 | 2 | 8 | 1 | 1 | 310 | 0 | 9 | 1 |
| 177 | 0 | 7 | 0 | 6 | 1 | 5 | 8 | 4 | 4 | 3 | 7 | 2 | 3 | 1 | 0 | 330 | 1 |
| 8 | 0 | 8 | 1 | 7 | 5 | 6 | 6 | 5 | 7 | 4 | 5 | 3 | 1 | 2 | 1 | 1 | 0 |
| 9 | 0 | 9 | 2 | 8 | 2 | 7 | 9 | 6 | 9 | 5 | 3 | 4 | 0 | 3 | 0 | 2 | 0 |
| 180 | 0 | 200 | 0 | 9 | 2 | 8 | 5 | 7 | 8 | 6 | 8 | 5 | 1 | 4 | 0 | 3 | 0 |
| 1 | 0 | 1 | 0 | 220 | 9 | 9 | 6 | 8 | 8 | 7 | 6 | 6 | 2 | 5 | 0 | 4 | 0 |
| 2 | 0 | 2 | 1 | 1 | 6 | 240 | 13 | 9 | 6 | 8 | 2 | 7 | 3 | 6 | 0 | 5 | 0 |
| 3 | 1 | 3 | 2 | 2 | 2 | 1 | 12 | 260 | 8 | 9 | 4 | 8 | 0 | 7 | 0 | 6 | 0 |
| 4 | 0 | 4 | 2 | 3 | 2 | 2 | 9 | 1 | 9 | 280 | 5 | 9 | 1 | 8 | 0 | 7 | 1 |
| 5 | 0 | 5 | 0 | 4 | 4 | 3 | 4 | 2 | 8 | 1 | 2 | 300 | 0 | 9 | 0 | 8 | 0 |
| 6 | 1 | 6 | 1 | 5 | 3 | 4 | 6 | 3 | 14 | 2 | 7 | 1 | 2 | 320 | 1 | 9 | 0 |
| 7 | 1 | 7 | 0 | 6 | 4 | 5 | 7 | 4 | 7 | 3 | 2 | 2 | 0 | 1 | 0 | 340 | 0 |
| 8 | 0 | 8 | 2 | 7 | 4 | 6 | 8 | 5 | 11 | 4 | 0 | 3 | 1 | 2 | 0 | 1 | 0 |
| 9 | 0 | 9 | 0 | 8 | 3 | 7 | 7 | 6 | 6 | 5 | 1 | 4 | 0 | 3 | 0 | 2 | 1 |
| 190 | 0 | 210 | 2 | 9 | 2 | 8 | 9 | 7 | 8 | 6 | 1 | 5 | 0 | 4 | 1 | 360 | 1 |
| 1 | 0 | 1 | 2 | 230 | 4 | 9 | 3 | 8 | 7 | 7 | 3 | 6 | 1 | 5 | 0 | 486 | 1 |
| 3 | 0 | 2 | 1 | 1 | 4 | 250 | 12 | 9 | 6 | 8 | 2 | 7 | 0 | 6 | 0 | 754 | 1 |
| 2 | 0 | 213 | 0 | 232 | 4 | 251 | 9 | 270 | 12 | 289 | 3 | 308 | 1 | 327 | 1 | 817 | 1 |
| 194 | 0 | | | | | | | | | | | | | | | | |

TWENTY-FIRST DAY, JULY 31, 1872.

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 75 | 1 | 193 | 0 | 209 | 0 | 225 | 7 | 241 | 10 | 257 | 8 | 273 | 1 | 288 | 0 | 303 | 0 |
| 137 | 1 | 4 | 0 | 210 | 1 | 6 | 7 | 2 | 7 | 8 | 7 | 4 | 4 | 9 | 3 | 4 | 0 |
| 160 | 1 | 5 | 0 | 1 | 3 | 7 | 7 | 3 | 10 | 9 | 10 | 5 | 2 | 290 | 1 | 5 | 0 |
| 161 | 2 | 6 | 1 | 2 | 1 | 8 | 6 | 4 | 8 | 260 | 5 | 6 | 3 | 1 | 2 | 6 | 0 |
| 181 | 1 | 7 | 1 | 3 | 3 | 9 | 9 | 5 | 3 | 1 | 11 | 7 | 1 | 2 | 2 | 7 | 0 |
| 2 | 0 | 8 | 2 | 4 | 0 | 230 | 8 | 6 | 10 | 2 | 6 | 8 | 3 | 3 | 2 | 8 | 0 |
| 3 | 1 | 9 | 0 | 5 | 3 | 1 | 10 | 7 | 11 | 3 | 8 | 9 | 4 | 4 | 0 | 9 | 0 |
| 4 | 0 | 200 | 1 | 6 | 5 | 2 | 6 | 8 | 11 | 4 | 6 | 280 | 4 | 5 | 0 | 310 | 0 |
| 5 | 1 | 1 | 3 | 7 | 5 | 3 | 10 | 9 | 9 | 5 | 7 | 1 | 1 | 6 | 0 | 1 | 0 |
| 6 | 0 | 2 | 2 | 8 | 2 | 4 | 4 | 250 | 7 | 6 | 3 | 2 | 2 | 7 | 1 | 2 | 1 |
| 7 | 0 | 3 | 0 | 9 | 2 | 5 | 8 | 1 | 8 | 7 | 7 | 3 | 1 | 8 | 1 | 3 | 1 |
| 8 | 0 | 4 | 2 | 220 | 9 | 6 | 8 | 2 | 8 | 8 | 5 | 4 | 0 | 9 | 1 | 331 | 1 |
| 9 | 2 | 5 | 2 | 1 | 4 | 7 | 11 | 3 | 9 | 9 | 3 | 5 | 4 | 300 | 0 | 348 | 1 |
| 190 | 0 | 6 | 3 | 2 | 6 | 8 | 9 | 4 | 7 | 270 | 4 | 6 | 1 | 1 | 0 | 349 | 1 |
| 1 | 2 | 7 | 0 | 3 | 5 | 9 | 10 | 5 | 10 | 1 | 1 | 287 | 5 | 302 | 1 | 438 | 1 |
| 192 | 1 | 208 | 2 | 224 | 3 | 240 | 10 | 256 | 10 | 272 | 3 | | | | | | |

TWENTY-SECOND DAY, AUGUST 1, 1872.

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 139 | 1 | 204 | 0 | 219 | 2 | 233 | 2 | 247 | 7 | 261 | 14 | 275 | 12 | 289 | 6 | 303 | 1 |
| 157 | 1 | 5 | 2 | 220 | 0 | 4 | 7 | 8 | 10 | 2 | 8 | 6 | 3 | 290 | 0 | 4 | 0 |
| 171 | 1 | 6 | 1 | 1 | 1 | 5 | 6 | 9 | 3 | 3 | 12 | 7 | 4 | 1 | 1 | 5 | 0 |
| 192 | 1 | 7 | 2 | 2 | 6 | 6 | 6 | 250 | 8 | 4 | 7 | 8 | 8 | 2 | 1 | 6 | 0 |
| 3 | 1 | 8 | 0 | 3 | 1 | 7 | 6 | 1 | 13 | 5 | 8 | 9 | 4 | 3 | 0 | 7 | 1 |
| 4 | 1 | 9 | 1 | 4 | 4 | 8 | 12 | 2 | 8 | 6 | 17 | 280 | 2 | 4 | 2 | 8 | 0 |
| 5 | 0 | 210 | 1 | 5 | 4 | 9 | 10 | 3 | 14 | 7 | 8 | 1 | 4 | 5 | 0 | 9 | 1 |
| 6 | 1 | 1 | 2 | 6 | 4 | 240 | 4 | 4 | 8 | 8 | 6 | 2 | 7 | 6 | 2 | 325 | 1 |
| 7 | 1 | 2 | 2 | 7 | 4 | 1 | 7 | 5 | 6 | 9 | 5 | 3 | 3 | 7 | 1 | 339 | 1 |
| 8 | 0 | 3 | 2 | 8 | 1 | 2 | 10 | 6 | 8 | 270 | 5 | 4 | 1 | 8 | 2 | 342 | 1 |
| 9 | 0 | 4 | 1 | 9 | 6 | 3 | 7 | 7 | 6 | 1 | 9 | 5 | 4 | 9 | 1 | 382 | 1 |
| 200 | 0 | 5 | 1 | 230 | 5 | 4 | 3 | 8 | 8 | 2 | 7 | 6 | 5 | 300 | 1 | 406 | 1 |
| 1 | 0 | 6 | 3 | 1 | 10 | 5 | 6 | 9 | 10 | 3 | 9 | 7 | 3 | 1 | 0 | 410 | 1 |
| 2 | 0 | 7 | 0 | 232 | 6 | 246 | 10 | 260 | 9 | 274 | 2 | 288 | 1 | 302 | 0 | 689 | 1 |
| 203 | 0 | 218 | 0 | | | | | | | | | | | | | | |

*Details of the experiments*—Continued.

TWENTY-THIRD DAY, AUGUST 2, 1872.

| Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. | Thousandths of a second. | Number of observations. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 142 | 1 | 184 | 0 | 202 | 1 | 220 | 1 | 238 | 5 | 256 | 10 | 274 | 7 | 292 | 0 | 310 | 1 |
| 166 | 1 | 5 | 1 | 3 | 0 | 1 | 6 | 9 | 9 | 7 | 10 | 5 | 3 | 3 | 4 | 1 | 0 |
| 7 | 2 | 6 | 0 | 4 | 1 | 2 | 5 | 240 | 8 | 8 | 11 | 6 | 1 | 4 | 1 | 2 | 0 |
| 8 | 0 | 7 | 0 | 5 | 0 | 3 | 6 | 1 | 8 | 9 | 9 | 7 | 3 | 5 | 2 | 3 | 0 |
| 9 | 0 | 8 | 0 | 6 | 1 | 4 | 5 | 2 | 7 | 260 | 8 | 8 | 4 | 6 | 0 | 4 | 1 |
| 170 | 0 | 9 | 1 | 7 | 1 | 5 | 6 | 3 | 12 | 1 | 9 | 9 | 7 | 7 | 0 | 5 | 0 |
| 1 | 0 | 190 | 0 | 8 | 0 | 6 | 4 | 4 | 9 | 2 | 13 | 280 | 3 | 8 | 2 | 6 | 1 |
| 2 | 2 | 1 | 0 | 9 | 0 | 7 | 3 | 5 | 7 | 3 | 6 | 1 | 2 | 9 | 0 | 7 | 0 |
| 3 | 0 | 2 | 0 | 210 | 1 | 8 | 4 | 6 | 7 | 4 | 11 | 2 | 3 | 300 | 0 | 8 | 0 |
| 4 | 0 | 3 | 1 | 1 | 0 | 9 | 5 | 7 | 6 | 5 | 7 | 3 | 4 | 1 | 0 | 9 | 0 |
| 5 | 1 | 4 | 0 | 2 | 3 | 230 | 4 | 8 | 6 | 6 | 6 | 4 | 1 | 2 | 1 | 320 | 0 |
| 6 | 0 | 5 | 0 | 3 | 3 | 1 | 9 | 9 | 12 | 7 | 8 | 5 | 0 | 3 | 0 | 1 | 0 |
| 7 | 0 | 6 | 3 | 4 | 2 | 2 | 8 | 250 | 9 | 8 | 8 | 6 | 3 | 4 | 0 | 2 | 1 |
| 8 | 0 | 7 | 0 | 5 | 4 | 3 | 6 | 1 | 8 | 9 | 6 | 7 | 1 | 5 | 0 | 3 | 1 |
| 9 | 1 | 8 | 0 | 6 | 1 | 4 | 6 | 2 | 10 | 270 | 14 | 8 | 1 | 6 | 1 | 340 | 1 |
| 180 | 1 | 9 | 0 | 7 | 0 | 5 | 6 | 3 | 12 | 1 | 3 | 9 | 1 | 7 | 0 | 371 | 1 |
| 1 | 0 | 200 | 0 | 8 | 5 | 6 | 4 | 4 | 9 | 2 | 7 | 290 | 2 | 8 | 0 | 406 | 1 |
| 2 | 0 | 201 | 0 | 219 | 2 | 237 | 2 | 255 | 5 | 273 | 4 | 291 | 1 | 309 | 1 | 661 | 1 |
| 183 | 1 | | | | | | | | | | | | | | | | |

TWENTY-FOURTH DAY, AUGUST 3, 1872.

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 119 | 1 | 198 | 2 | 213 | 3 | 228 | 9 | 243 | 12 | 257 | 12 | 271 | 3 | 285 | 1 | 299 | 0 |
| 134 | 1 | 9 | 1 | 4 | 4 | 9 | 4 | 4 | 10 | 8 | 5 | 2 | 1 | 6 | 4 | 300 | 0 |
| 156 | 1 | 200 | 2 | 5 | 1 | 230 | 7 | 5 | 16 | 9 | 8 | 3 | 4 | 7 | 0 | 1 | 0 |
| 172 | 1 | 1 | 1 | 6 | 1 | 1 | 11 | 6 | 9 | 260 | 6 | 4 | 1 | 8 | 1 | 2 | 1 |
| 175 | 1 | 2 | 0 | 7 | 4 | 2 | 12 | 7 | 7 | 1 | 9 | 5 | 5 | 9 | 0 | 3 | 0 |
| 188 | 2 | 3 | 0 | 8 | 7 | 3 | 18 | 8 | 11 | 2 | 2 | 6 | 0 | 290 | 2 | 4 | 0 |
| 9 | 0 | 4 | 1 | 9 | 5 | 4 | 5 | 9 | 13 | 3 | 6 | 7 | 2 | 1 | 0 | 5 | 0 |
| 190 | 1 | 5 | 1 | 220 | 3 | 5 | 7 | 250 | 13 | 4 | 4 | 8 | 0 | 2 | 4 | 6 | 0 |
| 1 | 0 | 6 | 1 | 1 | 6 | 6 | 11 | 1 | 14 | 5 | 1 | 9 | 0 | 3 | 0 | 7 | 2 |
| 2 | 1 | 7 | 1 | 2 | 3 | 7 | 10 | 2 | 14 | 6 | 1 | 280 | 3 | 4 | 3 | 8 | 0 |
| 3 | 0 | 8 | 2 | 3 | 1 | 8 | 8 | 3 | 12 | 7 | 2 | 1 | 2 | 5 | 0 | 9 | 1 |
| 4 | 0 | 9 | 6 | 4 | 4 | 9 | 8 | 4 | 12 | 8 | 2 | 2 | 1 | 6 | 0 | 334 | 1 |
| 5 | 0 | 210 | 3 | 5 | 8 | 240 | 6 | 5 | 6 | 9 | 3 | 3 | 1 | 7 | 1 | 340 | 1 |
| 6 | 0 | 1 | 3 | 6 | 6 | 1 | 9 | 256 | 8 | 270 | 3 | 284 | 0 | 298 | 0 | 374 | 1 |
| 197 | 0 | 212 | 3 | 227 | 5 | 242 | 8 | | | | | | | | | | |

# APPENDIX XXII.

# AZIMUTH AND APPARENT ALTITUDE OF POLARIS.

FOR

## FIELD USE IN PLACING THE MERIDIAN INSTRUMENT IN THE PLANE OF THE MERIDIAN.

COMPUTED WITH NORTH POLAR DISTANCE 1° 22′, AND MEAN REFRACTION,

BY

GEORGE DAVIDSON,

ASSISTANT UNITED STATES COAST SURVEY.

## AZIMUTH AND

| Hour angle before or after culm. | Latitude 30°. | | Latitude 32°. | | Latitude 34°. | | Latitude 36°. | | Latitude 38°. | | Latitude 40°. | | Latitude 42°. | | Latitude 44°. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Azim. | Alt. | Azim. | Alt. | Azim. | Alt. | Azim. | Alt. | Azim. | Alt. | Azim. | Alt. | Azim. | Alt. | Azim. | Alt. |
| h. m. | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ |
| 0 15 | 0 06 16 | 31 23 25 | 0 06 25 | 33 23 18 | 0 06 35 | 35 23 12 | 0 06 45 | 37 23 06 | 0 06 56 | 39 23 00 | 0 07 09 | 41 22 55 | 0 07 23 | 43 22 51 | 0 07 38 | 45 22 47 |
| 0 30 | 0 12 32 | 22 53 | 0 12 49 | 22 46 | 0 13 07 | 22 40 | 0 13 28 | 22 34 | 0 13 50 | 22 28 | 0 14 16 | 22 23 | 0 14 43 | 22 19 | 0 15 14 | 22 15 |
| 0 45 | 0 18 44 | 21 59 | 0 19 09 | 21 53 | 0 19 36 | 21 46 | 0 20 07 | 21 40 | 0 20 41 | 21 35 | 0 21 18 | 21 30 | 0 22 00 | 21 25 | 0 22 45 | 21 21 |
| 1 00 | 0 24 51 | 20 46 | 0 25 24 | 20 38 | 0 26 00 | 20 32 | 0 26 41 | 20 26 | 0 27 26 | 20 20 | 0 28 15 | 20 15 | 0 29 10 | 20 10 | 0 30 11 | 20 06 |
| 1 15 | 0 30 51 | 31 18 11 | 0 31 32 | 33 19 04 | 0 32 18 | 35 18 57 | 0 33 08 | 37 18 51 | 0 34 03 | 39 18 46 | 0 35 04 | 41 18 40 | 0 36 13 | 43 18 35 | 0 37 28 | 45 18 31 |
| 1 30 | 0 36 42 | 17 16 | 0 37 32 | 17 09 | 0 38 26 | 17 02 | 0 39 26 | 16 56 | 0 40 31 | 16 50 | 0 41 44 | 16 45 | 0 43 05 | 16 40 | 0 44 35 | 16 35 |
| 1 45 | 0 42 24 | 15 02 | 0 43 21 | 14 55 | 0 44 24 | 14 48 | 0 45 33 | 14 41 | 0 46 49 | 14 35 | 0 48 13 | 14 29 | 0 49 46 | 14 24 | 0 51 29 | 14 19 |
| 2 00 | 0 47 55 | 12 28 | 0 48 59 | 12 21 | 0 50 10 | 12 14 | 0 51 27 | 12 07 | 0 52 54 | 12 01 | 0 54 28 | 11 55 | 0 56 13 | 11 49 | 0 58 10 | 11 44 |
| 2 15 | 0 53 13 | 31 09 36 | 0 54 24 | 33 09 28 | 0 55 42 | 35 09 21 | 0 57 08 | 37 09 14 | 0 58 44 | 39 09 08 | 1 00 29 | 41 09 02 | 1 02 25 | 43 08 56 | 1 04 34 | 45 08 51 |
| 2 30 | 0 58 17 | 06 27 | 0 59 34 | 06 19 | 1 01 00 | 06 11 | 1 02 34 | 06 04 | 1 04 18 | 05 58 | 1 06 13 | 05 51 | 1 08 20 | 05 45 | 1 10 41 | 05 40 |
| 2 45 | 1 03 05 | 03 01 | 1 04 29 | 02 53 | 1 06 01 | 02 45 | 1 07 43 | 03 38 | 1 09 36 | 02 31 | 1 11 40 | 02 24 | 1 13 57 | 02 18 | 1 16 29 | 02 12 |
| 3 00 | 1 07 37 | 30 59 19 | 1 09 06 | 32 59 10 | 1 10 45 | 34 59 03 | 1 12 34 | 36 58 55 | 1 14 34 | 38 58 48 | 1 16 47 | 40 58 41 | 1 19 14 | 42 58 35 | 1 21 56 | 44 58 28 |
| 3 20 | 1 13 11 | 30 54 00 | 1 14 47 | 32 53 51 | 1 16 31 | 34 53 43 | 1 18 31 | 36 53 35 | 1 20 41 | 38 53 28 | 1 23 04 | 40 53 20 | 1 25 42 | 42 53 15 | 1 28 38 | 44 53 07 |
| 3 40 | 1 18 11 | 48 17 | 1 19 53 | 48 07 | 1 21 46 | 47 59 | 1 23 52 | 47 51 | 1 26 10 | 47 43 | 1 28 42 | 47 36 | 1 31 31 | 47 29 | 1 34 37 | 47 22 |
| 4 00 | 1 22 34 | 42 12 | 1 24 22 | 42 03 | 1 26 21 | 41 54 | 1 28 32 | 41 46 | 1 30 58 | 41 38 | 1 33 38 | 41 30 | 1 36 35 | 41 23 | 1 39 52 | 41 16 |
| 4 20 | 1 26 19 | 35 50 | 1 28 11 | 35 40 | 1 30 15 | 35 31 | 1 32 32 | 35 23 | 1 35 03 | 35 14 | 1 37 50 | 35 06 | 1 40 55 | 35 00 | 1 44 19 | 34 52 |
| 4 40 | 1 29 24 | 30 29 12 | 1 31 19 | 32 29 01 | 1 33 27 | 34 28 52 | 1 35 48 | 36 28 41 | 1 38 24 | 38 28 35 | 1 41 16 | 40 28 27 | 1 44 27 | 42 28 19 | 1 47 57 | 44 28 11 |
| 5 00 | 1 31 47 | 22 21 | 1 33 45 | 22 10 | 1 35 56 | 22 01 | 1 38 20 | 21 52 | 1 40 59 | 21 44 | 1 43 55 | 21 36 | 1 47 10 | 21 28 | 1 50 45 | 21 20 |
| 5 20 | 1 33 28 | 15 21 | 1 35 28 | 15 11 | 1 37 40 | 15 02 | 1 40 06 | 14 52 | 1 42 48 | 14 43 | 1 45 46 | 14 35 | 1 49 04 | 14 27 | 1 52 42 | 14 19 |
| Elon. | 1 34 41 | 30 02 15 | 1 36 42 | 32 02 10 | 1 38 55 | 34 02 06 | 1 41 22 | 36 02 03 | 1 44 04 | 38 02 00 | 1 47 03 | 40 01 59 | 1 50 21 | 42 01 58 | 1 54 00 | 44 01 57 |
| Elon. at | h. m. s. 5 56 51 | | h. m. s. 5 56 35 | | h. m. s. 5 56 19 | | h. m. s. 5 56 02 | | h. m. s. 5 55 44 | | h. m. s. 5 55 25 | | h. m. s. 5 55 05 | | h. m. s. 5 54 43 | |
| 6 40 | 1 33 01 | 29 46 55 | 1 34 58 | 31 46 44 | 1 37 08 | 33 46 34 | 1 39 31 | 35 46 26 | 1 42 08 | 37 46 17 | 1 45 02 | 39 46 08 | 1 48 15 | 41 46 00 | 1 51 48 | 43 45 52 |
| 7 00 | 1 31 08 | 39 58 | 1 33 02 | 39 47 | 1 35 08 | 39 38 | 1 37 28 | 39 28 | 1 40 01 | 39 20 | 1 42 51 | 39 11 | 1 45 59 | 39 03 | 1 49 26 | 38 55 |
| 7 20 | 1 28 33 | 33 11 | 1 30 24 | 33 00 | 1 32 26 | 32 51 | 1 34 41 | 32 42 | 1 37 09 | 32 33 | 1 39 54 | 32 25 | 1 42 55 | 32 17 | 1 46 16 | 32 09 |
| 7 40 | 1 25 19 | 26 36 | 1 27 05 | 26 26 | 1 29 02 | 26 16 | 1 31 11 | 26 08 | 1 33 34 | 25 59 | 1 36 12 | 25 52 | 1 39 06 | 25 44 | 1 42 18 | 25 36 |
| 8 00 | 1 21 26 | 29 20 19 | 1 23 07 | 31 20 09 | 1 24 58 | 33 19 59 | 1 27 01 | 35 19 51 | 1 29 17 | 37 19 43 | 1 31 47 | 39 19 35 | 1 34 32 | 41 19 27 | 1 37 35 | 43 19 20 |
| 8 20 | 1 16 57 | 14 20 | 1 18 32 | 14 10 | 1 20 17 | 14 01 | 1 22 13 | 13 53 | 1 24 20 | 13 45 | 1 26 41 | 13 37 | 1 29 17 | 13 30 | 1 32 09 | 13 23 |
| 8 40 | 1 11 54 | 08 42 | 1 13 22 | 08 33 | 1 14 59 | 08 24 | 1 16 48 | 08 17 | 1 18 46 | 08 08 | 1 20 58 | 08 01 | 1 23 22 | 07 54 | 1 26 03 | 07 47 |
| 9 00 | 1 06 19 | 03 29 | 1 07 42 | 03 20 | 1 09 09 | 03 11 | 1 10 48 | 03 04 | 1 12 38 | 02 56 | 1 14 38 | 02 49 | 1 16 51 | 02 42 | 1 19 19 | 02 36 |
| 9 15 | 1 01 48 | 28 59 51 | 1 03 03 | 30 59 42 | 1 04 26 | 32 59 34 | 1 05 58 | 34 59 26 | 1 07 40 | 36 59 19 | 1 09 32 | 38 59 12 | 1 11 36 | 40 59 06 | 1 13 53 | 42 58 59 |
| 9 30 | 0 57 01 | 56 30 | 0 58 11 | 56 21 | 0 59 28 | 56 12 | 1 00 52 | 56 05 | 1 02 26 | 55 58 | 1 04 09 | 55 51 | 1 06 03 | 55 45 | 1 08 09 | 55 39 |
| 9 45 | 0 52 00 | 53 25 | 0 53 04 | 53 16 | 0 54 14 | 53 08 | 0 55 31 | 53 00 | 0 56 56 | 52 53 | 0 58 30 | 52 47 | 1 00 14 | 52 41 | 1 02 09 | 52 35 |
| 10 00 | 0 46 47 | 50 37 | 0 47 44 | 50 28 | 0 48 47 | 50 20 | 0 49 56 | 50 13 | 0 51 13 | 50 06 | 0 52 37 | 49 59 | 0 54 10 | 49 54 | 0 55 53 | 49 48 |
| 10 15 | 0 41 22 | 28 48 07 | 0 42 12 | 30 47 58 | 0 43 08 | 32 47 50 | 0 44 09 | 34 47 43 | 0 45 16 | 36 47 37 | 0 46 31 | 38 47 31 | 0 47 53 | 40 47 25 | 0 49 24 | 42 47 20 |
| 10 30 | 0 35 47 | 45 56 | 0 36 30 | 45 47 | 0 37 18 | 45 39 | 0 38 11 | 45 32 | 0 39 09 | 45 26 | 0 40 14 | 45 20 | 0 41 25 | 45 15 | 0 42 43 | 45 10 |
| 10 45 | 0 30 03 | 44 04 | 0 30 39 | 43 56 | 0 31 19 | 43 48 | 0 32 04 | 43 41 | 0 32 52 | 43 35 | 0 33 46 | 43 29 | 0 34 46 | 43 24 | 0 35 52 | 43 19 |
| 11 00 | 0 24 11 | 42 32 | 0 24 40 | 42 24 | 0 25 13 | 42 16 | 0 25 48 | 42 09 | 0 26 28 | 42 03 | 0 27 11 | 41 57 | 0 27 59 | 41 52 | 0 28 52 | 41 47 |
| 11 15 | 0 18 14 | 28 41 20 | 0 18 36 | 30 41 11 | 0 19 00 | 32 41 04 | 0 19 27 | 34 40 57 | 0 19 56 | 36 40 51 | 0 20 29 | 38 40 47 | 0 21 05 | 40 40 41 | 0 21 45 | 42 40 36 |
| 11 30 | 0 12 12 | 40 28 | 0 12 26 | 40 20 | 0 12 43 | 40 12 | 0 13 00 | 40 06 | 0 13 29 | 40 00 | 0 13 42 | 39 54 | 0 14 06 | 39 49 | 0 14 33 | 39 44 |
| 11 45 | 0 06 07 | 39 57 | 0 06 14 | 39 49 | 0 06 22 | 39 41 | 0 06 31 | 39 35 | 0 06 41 | 39 29 | 0 06 52 | 39 23 | 0 07 04 | 39 18 | 0 07 17 | 39 14 |
| h. m. | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ |
| | Azim. | Alt. | Azim. | Alt. | Azim. | Alt. | Azim. | Alt. | Azim. | Alt. | Azim. | Alt. | Azim. | A t. | Azim. | Alt. |
| Hour angle before or after culm. | Latitude 30°. | | Latitude 32°. | | Latitude 34°. | | Latitude 36°. | | Latitude 38°. | | Latitude 40°. | | Latitude 42°. | | Latitude 44°. | |

## APPARENT ALTITUDE OF POLARIS.

| Latitude 46°. | | Latitude 48°. | | Latitude 50°. | | Latitude 52°. | | Latitude 54°. | | Latitude 56°. | | Latitude 58°. | | Latitude 60°. | | Hour angle before or after culm. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Azim. | Alt. | Azim. | Alt. | Azim. | Alt. | Azim. | Alt. | Azim. | Alt. | Azim. | Alt. | Azim. | Alt. | Azim. | Alt. | |
| ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | h. m. |
| 0 07 55 | 47 22 43 | 0 08 14 | 49 22 39 | 0 08 35 | 51 22 36 | 0 08 59 | 53 22 32 | 0 09 26 | 55 22 29 | 0 09 57 | 57 22 26 | 0 10 31 | 59 22 23 | 0 11 11 | 61 22 20 | 0 15 |
| 0 15 48 | 22 11 | 0 16 26 | 22 07 | 0 17 08 | 22 04 | 0 17 56 | 22 00 | 0 18 50 | 21 57 | 0 19 50 | 21 54 | 0 21 00 | 21 51 | 0 22 19 | 21 48 | 0 30 |
| 0 23 36 | 21 17 | 0 24 33 | 21 13 | 0 25 36 | 21 10 | 0 26 47 | 21 06 | 0 28 08 | 21 03 | 0 29 38 | 21 00 | 0 31 22 | 20 56 | 0 33 21 | 20 53 | 0 45 |
| 0 31 18 | 20 02 | 0 32 34 | 19 58 | 0 33 57 | 19 54 | 0 35 31 | 19 51 | 0 37 18 | 19 47 | 0 39 18 | 19 44 | 0 41 35 | 19 40 | 0 44 13 | 19 37 | 1 00 |
| 0 38 52 | 47 18 26 | 0 40 25 | 49 18 22 | 0 42 09 | 51 18 18 | 0 44 06 | 53 18 14 | 0 46 17 | 55 18 11 | 0 48 40 | 57 18 07 | 0 51 37 | 59 18 03 | 0 54 52 | 61 18 00 | 1 15 |
| 0 46 14 | 16 30 | 0 48 05 | 16 26 | 0 50 08 | 16 22 | 0 52 27 | 16 18 | 0 55 04 | 16 14 | 0 58 01 | 16 10 | 1 01 23 | 16 06 | 1 05 15 | 16 02 | 1 30 |
| 0 53 24 | 14 11 | 0 55 32 | 14 10 | 0 57 54 | 14 05 | 1 00 34 | 14 01 | 1 03 35 | 13 57 | 1 06 59 | 13 53 | 1 10 52 | 13 48 | 1 15 20 | 13 44 | 1 45 |
| 1 00 19 | 11 39 | 1 02 43 | 11 34 | 1 05 24 | 11 30 | 1 08 24 | 11 25 | 1 11 48 | 11 20 | 1 15 38 | 11 16 | 1 20 01 | 11 11 | 1 25 03 | 11 06 | 2 00 |
| 1 06 58 | 47 08 46 | 1 09 37 | 49 08 41 | 1 12 36 | 51 08 36 | 1 15 56 | 53 08 31 | 1 19 41 | 55 08 26 | 1 23 56 | 57 08 20 | 1 28 47 | 59 08 15 | 1 34 21 | 61 08 09 | 2 15 |
| 1 13 18 | 05 34 | 1 16 12 | 05 29 | 1 19 27 | 05 24 | 1 23 06 | 05 19 | 1 27 12 | 05 13 | 1 32 50 | 05 08 | 1 37 08 | 05 02 | 1 43 12 | 04 56 | 2 30 |
| 1 19 18 | 02 06 | 1 22 27 | 02 01 | 1 25 57 | 01 55 | 1 29 53 | 01 49 | 1 34 18 | 01 43 | 1 39 19 | 01 38 | 1 45 02 | 01 32 | 1 51 35 | 01 26 | 2 45 |
| 1 24 57 | 46 58 22 | 1 28 18 | 48 58 16 | 1 32 03 | 50 58 10 | 1 36 15 | 52 58 04 | 1 40 59 | 54 57 58 | 1 46 20 | 56 57 52 | 1 52 26 | 58 57 46 | 1 59 26 | 60 57 40 | 3 00 |
| 1 31 53 | 46 53 01 | 1 35 30 | 48 52 54 | 1 39 32 | 50 52 48 | 1 44 04 | 52 52 42 | 1 49 09 | 54 52 35 | 1 54 56 | 56 52 28 | 2 01 30 | 58 52 21 | 2 09 01 | 60 52 14 | 3 20 |
| 1 38 05 | 47 15 | 1 41 54 | 47 08 | 1 46 13 | 47 02 | 1 51 02 | 46 55 | 1 56 27 | 46 48 | 2 02 35 | 46 40 | 2 09 34 | 46 33 | 2 17 33 | 46 25 | 3 40 |
| 1 43 30 | 41 09 | 1 47 32 | 41 02 | 1 52 03 | 40 54 | 1 57 07 | 40 47 | 2 02 48 | 40 40 | 2 09 15 | 40 32 | 2 16 34 | 40 24 | 2 24 58 | 40 15 | 4 00 |
| 1 48 06 | 34 44 | 1 52 18 | 34 36 | 1 57 00 | 34 29 | 2 02 16 | 34 22 | 2 08 11 | 34 14 | 2 14 52 | 34 06 | 2 22 29 | 33 57 | 2 31 12 | 33 47 | 4 20 |
| 1 51 51 | 46 28 04 | 1 56 11 | 48 27 56 | 2 01 01 | 50 27 48 | 2 06 27 | 52 27 41 | 2 12 32 | 54 27 32 | 2 19 20 | 56 27 24 | 2 27 16 | 58 27 14 | 2 36 15 | 60 27 05 | 4 40 |
| 1 54 44 | 21 12 | 1 59 10 | 21 04 | 2 04 06 | 20 56 | 2 09 38 | 20 48 | 2 15 52 | 21 39 | 2 22 54 | 20 30 | 2 30 54 | 20 21 | 2 40 02 | 20 11 | 5 00 |
| 1 56 44 | 14 11 | 2 01 13 | 14 03 | 2 06 13 | 13 55 | 2 11 50 | 13 46 | 2 18 08 | 13 38 | 2 25 15 | 13 29 | 2 33 20 | 13 19 | 2 42 35 | 13 08 | 5 20 |
| 1 58 03 | 46 01 57 | 2 02 34 | 48 01 58 | 2 07 35 | 50 01 59 | 2 13 13 | 52 02 01 | 2 19 32 | 54 02 03 | 2 26 40 | 56 02 06 | 2 34 47 | 58 02 10 | 2 44 03 | 60 02 15 | Elon. |
| h. m. s. | | h. m. s. | | h. m. s. | | h. m. s. | | h. m. s. | | h. m. s. | | h. m. s. | | h. m. s. | | |
| 5 54 20 | | 5 53 56 | | 5 53 29 | | 5 53 00 | | 5 52 28 | | 5 51 54 | | 5 51 15 | | 5 50 32 | | Elon. at } |
| 1 55 44 | 45 45 44 | 2 00 06 | 47 45 36 | 2 04 59 | 49 45 28 | 2 10 26 | 51 45 19 | 2 16 34 | 53 45 11 | 2 23 28 | 55 45 02 | 2 31 19 | 57 44 52 | 2 40 16 | 59 44 42 | 6 40 |
| 1 53 17 | 38 48 | 1 57 32 | 38 40 | 2 02 18 | 38 32 | 2 07 36 | 38 23 | 2 13 34 | 38 15 | 2 20 18 | 38 06 | 2 27 56 | 37 57 | 2 36 39 | 37 47 | 7 00 |
| 1 49 59 | 32 02 | 1 54 06 | 31 54 | 1 58 42 | 31 46 | 2 03 50 | 31 38 | 2 09 36 | 31 30 | 2 16 06 | 31 22 | 2 23 29 | 31 13 | 2 31 54 | 31 04 | 7 20 |
| 1 45 52 | 25 29 | 1 49 49 | 25 22 | 1 54 13 | 25 14 | 1 59 09 | 25 06 | 2 04 40 | 24 59 | 2 10 54 | 24 51 | 2 17 58 | 24 42 | 2 26 01 | 24 33 | 7 40 |
| 1 40 58 | 45 19 13 | 1 44 44 | 47 19 06 | 1 48 55 | 49 18 59 | 1 53 36 | 51 18 50 | 1 58 50 | 53 18 43 | 2 04 45 | 55 18 36 | 2 11 28 | 57 18 29 | 2 19 06 | 59 18 20 | 8 00 |
| 1 35 20 | 13 16 | 1 38 52 | 13 09 | 1 42 49 | 13 02 | 1 47 13 | 12 56 | 1 52 09 | 12 49 | 1 57 42 | 12 42 | 2 04 01 | 12 34 | 2 11 12 | 12 27 | 8 20 |
| 1 29 01 | 07 41 | 1 32 18 | 07 34 | 1 35 58 | 07 28 | 1 40 03 | 07 22 | 1 44 39 | 07 15 | 1 49 49 | 07 08 | 1 55 41 | 07 02 | 2 02 21 | 06 54 | 8 40 |
| 1 22 02 | 02 30 | 1 25 04 | 02 24 | 1 28 26 | 02 18 | 1 32 11 | 02 12 | 1 36 24 | 02 06 | 1 41 09 | 02 00 | 1 46 32 | 01 53 | 1 52 39 | 01 47 | 9 00 |
| 1 16 25 | 44 58 54 | 1 19 13 | 46 58 48 | 1 22 21 | 48 58 42 | 1 25 51 | 50 58 37 | 1 29 46 | 52 58 31 | 1 34 10 | 54 58 26 | 1 39 10 | 56 58 20 | 1 44 52 | 58 58 14 | 9 15 |
| 1 10 29 | 55 33 | 1 13 04 | 55 28 | 1 15 57 | 55 22 | 1 19 10 | 55 17 | 1 22 46 | 55 12 | 1 26 50 | 55 07 | 1 31 26 | 55 02 | 1 36 40 | 54 56 | 9 30 |
| 1 04 16 | 52 30 | 1 06 37 | 52 24 | 1 09 14 | 52 19 | 1 12 10 | 52 14 | 1 15 27 | 52 10 | 1 19 08 | 52 04 | 1 23 19 | 52 00 | 1 28 05 | 51 54 | 9 45 |
| 0 57 48 | 49 43 | 0 59 54 | 49 38 | 1 02 15 | 49 33 | 1 04 53 | 49 28 | 1 07 50 | 49 24 | 1 11 09 | 49 19 | 1 14 54 | 49 15 | 1 19 10 | 49 10 | 10 00 |
| 0 51 05 | 44 47 15 | 0 52 57 | 46 47 10 | 0 55 02 | 48 47 05 | 0 57 21 | 50 47 01 | 0 59 57 | 52 46 57 | 1 02 52 | 54 46 52 | 1 06 11 | 56 46 48 | 1 09 57 | 58 46 44 | 10 15 |
| 0 44 10 | 45 05 | 0 45 47 | 45 00 | 0 47 34 | 44 56 | 0 49 35 | 44 52 | 0 51 49 | 44 47 | 0 54 21 | 44 43 | 0 57 12 | 44 40 | 1 00 27 | 44 36 | 10 30 |
| 0 37 05 | 43 14 | 0 38 26 | 43 10 | 0 39 56 | 43 05 | 0 41 37 | 43 01 | 0 43 30 | 42 57 | 0 45 37 | 42 53 | 0 48 01 | 42 50 | 0 50 44 | 42 46 | 10 45 |
| 0 29 51 | 41 43 | 0 30 56 | 41 38 | 0 32 08 | 41 34 | 0 33 29 | 41 30 | 0 35 00 | 41 27 | 0 36 42 | 41 23 | 0 38 38 | 41 20 | 0 40 49 | 41 16 | 11 00 |
| 0 22 29 | 44 40 31 | 0 23 18 | 46 40 27 | 0 24 13 | 48 40 23 | 0 25 14 | 50 40 20 | 0 26 22 | 52 40 16 | 0 27 39 | 54 40 13 | 0 29 06 | 56 40 10 | 0 30 45 | 58 40 07 | 11 15 |
| 0 15 03 | 39 40 | 0 15 35 | 39 36 | 0 16 12 | 39 32 | 0 16 52 | 39 28 | 0 17 38 | 39 25 | 0 18 30 | 39 22 | 0 19 28 | 39 19 | 0 20 34 | 39 16 | 11 30 |
| 0 07 32 | 39 00 | 0 07 49 | 39 05 | 0 08 07 | 39 01 | 0 08 27 | 38 58 | 0 08 50 | 38 54 | 0 09 16 | 38 51 | 0 09 45 | 38 48 | 0 10 18 | 38 45 | 11 45 |
| ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | h. m. |
| Azim. | Alt. | Azim. | Alt. | Azim. | Alt. | Azim. | Alt. | Azim. | Alt. | Azim. | Alt. | Azim. | Alt. | Azim. | Alt. | Hour angle before or after culm. |
| Latitude 46°. | | Latitude 48°. | | Latitude 50°. | | Latitude 52°. | | Latitude 54°. | | Latitude 56°. | | Latitude 58°. | | Latitude 60°. | | |

# LIST OF SKETCHES.

NOTE.—Sketches Nos. 22 and 30 will be published in the 1871 Report.

# APPENDIX No. 16*a*.

REPORT ON THE ECLIPSE OF THE SUN ON THE 22D OF DECEMBER, 1870. BY BENJAMIN PEIRCE, LL.D., SUPERINTENDENT UNITED STATES COAST SURVEY.

(From the Coast Survey Report for 1871.)

Certain astronomical phenomena of rare occurrence and high importance for the advancement of human knowledge have, in all civilized countries, since modern science has been cultivated, been deemed matters of national importance. Among these are total eclipses of the sun; and for many years it has been customary for the great nations to organize expeditions for the observation of them.

The first total eclipse visible in this country since the formation of the Government was that of June, 1806. This was accurately observed at several points, and a valuable painting was made of it. We were not favored with another until November 30, 1834, when the moon's shadow passed over the continent from northwest to southeast. This eclipse was observed by R. T. Paine, esq., of Boston, at Beaufort, South Carolina. A third eclipse did not visit our country until 1860; hence, at that time this wonderful phenomenon was for most American astronomers a matter of hearsay.*

The path of the eclipse of July 18, 1860, was from Washington Territory to the northern shore of Labrador, and thence across the ocean to Spain. This eclipse was observed by expeditions organized under the Superintendent of the Coast Survey, and the results are published in the report for that year. It was also observed by the astronomers of several governments abroad, and was the first total eclipse which was photographed. In 1868 British, French, and German expeditions were fitted out for the observation of a total eclipse in India. On this occasion brilliant discoveries were made in regard to the spectrum of certain rose-colored prominences seen about the sun at such times; and these discoveries have been increasing in interest ever since. In 1869 another total eclipse was visible in the United States. It was observed by parties organized by the Coast Survey and other Government bureaus. The results were of high importance. Photographs of the whole corona were taken for the first time; the first observations were made upon the spectrum of the corona; the radial polarization of the corona was first observed with care, while the former knowledge of the subject was advanced in every direction. The results of these two eclipses were of such importance in regard to one of the chief scientific problems of our time—the constitution of the sun—as to excite the profoundest interest throughout the world. It was felt by everybody even casually interested in science that the eclipse of 1870 afforded an opportunity for removing the last obscurity from the subject of the corona, such as ought not to be let slip, the more so as no other eclipse was expected to be observed during this century.† In accordance with these views the Hon. John A. Bingham, of Ohio, introduced a joint resolution, which was approved by Congress and the Executive, authorizing the fitting out of an American expedition, such as were to be sent out by Germany, by France, by Great Britain, by Italy, and by Spain, to study the phenomena of this eclipse. The late unhappy war prevented the first two nations from sparing any of their energy for this peaceful emulation, but extensive preparations were made by all the others. The American and English parties were in co-operation, and afforded each other mutual aid. It is hoped that the good feeling thus engendered was not without influence beyond the circle of science. The observations of this eclipse had for their general result the triumphant vindication of the American observations of the year before, the novelty of which had made them somewhat

* Mr. G. P. Bond had observed the eclipse of 1851 in Sweden.

† Nevertheless, the British government has sent out parties to another eclipse in 1871, in India and Australia; and three American astronomers have been invited, through the Superintendent of the Coast Survey, to join the expedition.

suspected in Europe, as well as the establishment of the superior accuracy of the American lunar predictions. Some new features were observed in the corona and in the chromosphere, and other observations were multiplied. This is, however, not the place for entering upon the details of scientific proceedings, which will be given with all desirable fullness in the Appendix.

With a view of selecting localities where astronomical conditions, as well as those of the weather, might be expected to be favorable for observation, Mr. Charles S. Peirce proceeded to Europe in advance, under my direction, and after visiting Italy, Spain, and European Turkey, recommended the occupation of stations in Southern Spain and in Sicily. The country east of Italy, over which the track of the totality passed, had the sun too low for photographic purposes. Considering the probable distribution along the line of totality of the European astronomers, I decided, finally, to dispatch two parties, one to be stationed in the vicinity of Jerez, in Spain, the other, under my immediate personal direction, to occupy positions on the Island of Sicily, in the neighborhood of Catania. In selecting observers I availed myself of such as had previous experience, which, in matters pertaining to solar eclipses, is of much importance, and whose former services in the special lines of duty assigned gave full assurance that no fact that could possibly be noted under the circumstances would be lost.

The party organized for service in Sicily had the threefold duty assigned of making measures of precision, including the determination of the geographical position and local time of contact, of getting photographic impressions of the various phases of the eclipse and of the corona, and of analyzing the corona by means of the polariscope and spectroscope. Accompanying phenomena were also to be recorded. To improve as much as possible the chances of the weather the party was spread over as large an area as could conveniently be included, a precaution which proved of great value, as may be gathered from the account of the labors of the party.

A most cordial co-operation with the party of British observers, several members of which took position at Catania, was maintained throughout our stay. While in England and on the Continent, on my way to the place of observation, the opportunity was taken to procure additional instruments required for our purpose.

The party is indebted to Mr. Wilding, our vice consul at Liverpool, and to Signor Cattaneo, Italian consul at that port, for affording facilities to pass our instruments through the Messina custom-house. Our thanks are especially due, for most effective assistance rendered in receiving, storing, and forwarding our instruments and reshipping them to New York, to our consul, Mr. F. W. Behn, at Messina, and the vice-consul, Mr. Augustus Peratoner, at Catania. We were indebted, also, to Professor Lorenzo Madden and Professor Orazio Silvestri, of Catania, for assistance, and to the municipal authorities for permission to use the grounds occupied by the observers.

The distribution of the party in the vicinity of Catania, and the nature of the results secured, will be briefly mentioned.

Our principal station was in the garden of the Benedictine Convent of St. Nicola, in the western part of the city, a position selected by Assistant Charles A. Schott, who determined, early in December, the latitude and longitude, and also the local time. L. M. Rutherford, esq., of New York, provided photographic apparatus for use, by Mr. H. G. Fitz, optician, who was sent in charge of the equatorial, and was assisted by Mr. D. C. Chapman and Mr. Burgess, photographers. For determining time and latitude Mr. Schott used the portable meridian-telescope, C. S. No. 9, and siderial chronometer, Kessels, 1287, which was rated at Washington, and checked at London, Berlin, Munich, and Naples. For local-time comparisons the party is indebted to Dr. Förster, director of the Berlin observatory; to Dr. Lamont, director of the Munich observatory; and to Professor de Gasparis, director, and Mr. Fergola, assistant, of the observatory at Cape di Monte at Naples.

Transits were recorded on five nights, and thirteen pairs of stars were observed for latitude; the longitude depends upon that of Naples and Munich. In order to secure accuracy, Mr. H. H. D. Peirce compared chronometer times at Syracuse with the party of observers from the United States Naval Observatory, thus verifying the determination for longitude of the respective stations. A number of chronometers were in advance rated for the use of observers, and a small triangulation was made, uniting the eclipse stations in the garden with the triangulation by Dr. Peters and

Baron Waltershausen, who surveyed that vicinity previous to the year 1841. It is gratifying to note the very close accordance between the earlier astronomical determinations and those taken thirty years afterward. Time signals by heliotropes were sent and received by the observers at Catania, and at the Monte-Rossi station. Mr. Schott included, in his series of geographical positions, the three places occupied in the garden of the convent, two by the English party in charge of Mr. J. Norman Lockyer, and the other by Mr. J. H. Lane, of the Office of United States Weights and Measures, who, though fully prepared for spectroscopic observations, was prevented by unfavorable weather from recording special results. The photographic party secured forty-five negatives of the sun, seventeen during the eclipse and before totality, and fourteen after it, at irregular intervals, taking advantage of breaks in the clouds. The direction of a parallel of declination was indicated by the image of a thread, so adjusted before the eclipse that a solar spot might be seen as moving along the thread during the transit. Mr. Fitz operated the equatorial and timed the pictures. An attempt was made by means of an ordinary camera to secure an impression during the momentary appearance of a portion of the corona. The time of the first contact was noted by Mr. Schott, who was apprised by a pistol fired by a member of the English party, (the report by preconcert,) indicating that Mr. Lockyer had already spectroscopically noted the approach of the moon's limb over the solar chromosphere. The dense clouds which came from the direction of Mount Etna, and to the west of it, defeated all attempts at observing the times of the inner contacts and of the last contact. Mr. Schott, however, saw, through a rift in the clouds, a part of the corona, to the northward and eastward of the sun's center, for about three seconds. It appeared in sharp outline nearly concentric with the moon's limb, of white silvery light, extending, by estimation, to about one-third of the moon's radius. The light tint of orange-yellow usually accompanying total eclipses was seen about the southern and eastern horizon. The first contact or beginning of the eclipse, as predicted from data in the American Ephemeris, was only 3.9 seconds earlier than the time actually noted in observing at Catania.

My own station was about three miles north of Catania, at the villa of the Marquis di San Giuliano, whose obliging courtesy is a subject of grateful remembrance. There the weather was more favorable than at the city, and afforded a full view of the corona, the study of which was made a special object. Mr. C. S. Peirce observed with a polariscope and obtained good results. Mrs. C. S. Peirce was successful in drawing the corona, and distinctly recognized the dark rifts which have become a subject of discussion, and which were photographed by Mr. Brothers, of the British party, at another station. Farther north were stationed Brevet Brigadier General H. L. Abbot, United States Engineers, Professor Roscoe, of England, and Signor Amerigo da Schio, Dr. Vogel, of Berlin, and others. Their object was to observe the phenomena of the eclipse at the greatest possible height on the southern slope of Mount Etna, for comparison with similar observations taken at stations near the sea-level. It is much to be regretted that this party was overtaken by a snow-storm which obscured the sky, and obliged them to descend during the time of the eclipse.

A few miles to the westward and northward of Catania, at one of the trigonometrical signals on the western peak of Monte Rossi, Dr. C. H. F. Peters, of Hamilton College, Clinton, New York and Sub-Assistant W. Eimbeck selected a position for observing the eclipse. Dr. Peters had a spectroscope apparatus, and Mr. Eimbeck a comet-seeker. This party also had unfavorable weather, but succeeded in noting the times of the first contact and of the last contact; the last through thick haze. The interior contacts were lost on account of a passing hail-storm. Mr. Eimbeck also assisted Mr. Schott in recording transits and other observations at Catania.

Professor J. C. Watson, of Ann Arbor, Michigan, occupied a station on the high ground near Carlentini. The weather there was favorable during the time of totality. Professor Watson made observations, which resulted in two colored drawings of the corona of unrivaled fullness of detail and accuracy. Dr. T. W. Parsons, at Syracuse, also made an elaborate colored representation of the eclipse.

It will thus be seen that my party in Sicily were distributed to the north of the track of total eclipse, while stations to the south of it were occupied by the party from the United States Naval Observatory. Stations on the central line were occupied by the Italian astronomers, including the Padre Secchi, Professor Cacciatore, and others.

A detailed account of the results of observations will be found in the Appendix No. 16 of the report of 1870.

I take this opportunity to mention the kindness of Henry Suter, esq., Her Britannic Majesty's vice-consul at Larissa and Volo, who, when it was contemplated to send a party to Larissa, afforded every facility for the prosecution of inquiries, and was in readiness to assist further if it had been expedient to occupy a station near that city.

# National Oceanic and Atmospheric Administration

## Annual Report of the Superintendent of the Coast Survey

### Please Note:

This project currently includes the imaging of the full text of each volume up to the "List of Sketches" (maps) at the end. Future online links, by the National Ocean Service, located on the Historical Map and Chart Project webpage (http://historicals.ncd.noaa.gov/historicals/histmap.asp) will includes these images.