# MEMOIRS

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# NATIONAL ACADEMY OF SCIENCES.

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# MEMOIRS.

1. Report of the Eclipse Expedition to Caroline Island, May 1883.

2. Experimental Determination of Wave-Lengths in the Invisible Prismatic Spectrum; by Prof. S. P. Langley.

3. On the Subsidence of Particles in Liquids; by Prof. W. H. Brewer.

4. On the Formation of a Deaf Variety of the Human Race; by A. Graham Bell.

NATIONAL ACADEMY OF SCIENCES.

# FIRST MEMOIR.

# REPORT

OF THE

# ECLIPSE EXPEDITION TO CAROLINE ISLAND MAY, 1883.

## LETTER OF TRANSMITTAL.

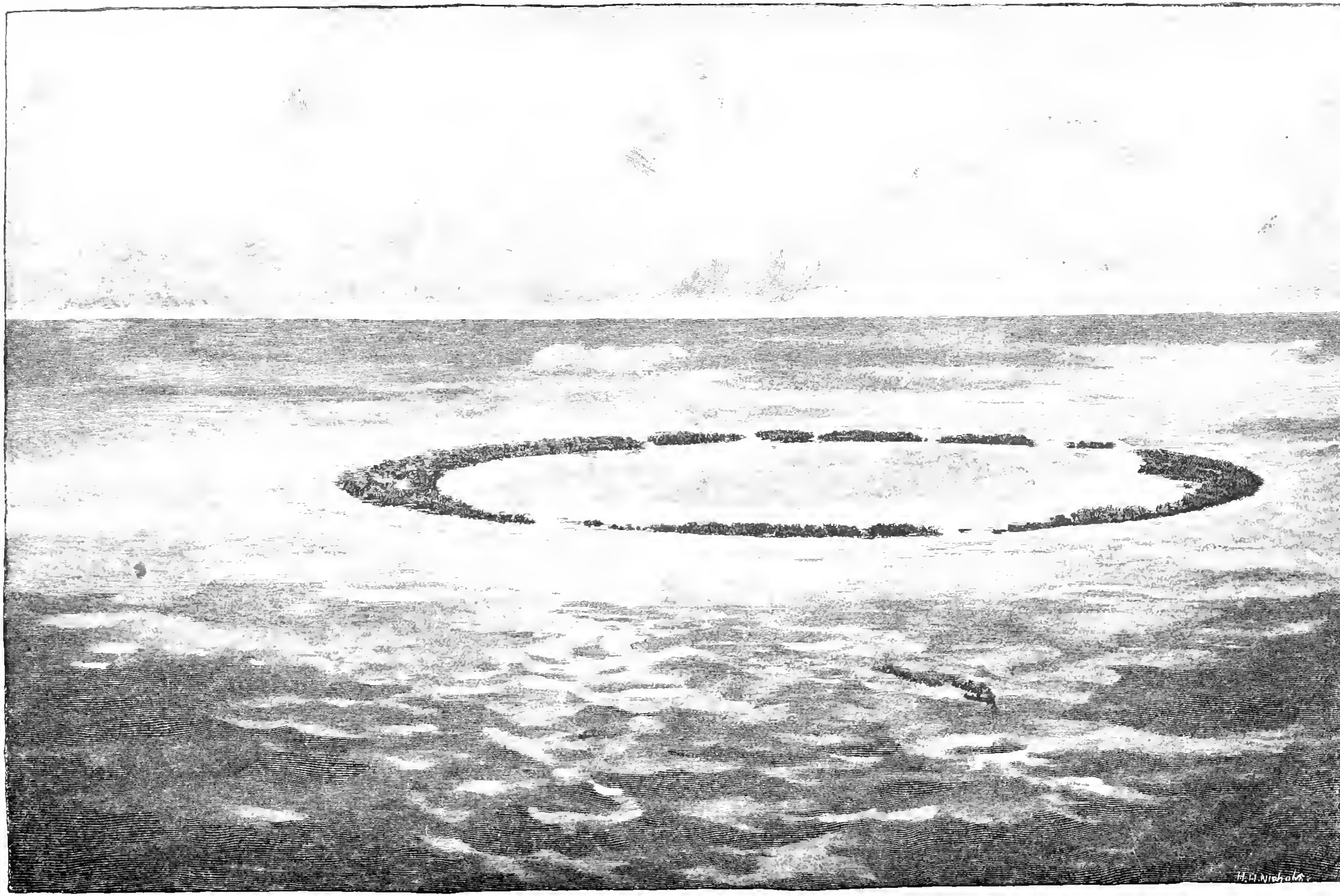
PRINCETON COLLEGE,
*Princeton, N. J., December 22, 1883.*

SIR: I have the honor to transmit to you, through the hands of Professor Coffin, the report of the committee of the Academy, to which was intrusted the arrangements for securing observations of the eclipse of May, 1883. It contains the reports and observations of Professor Holden and his associates in the expedition, and I have, in compliance with a request of the committee, prefixed a brief introduction, giving an account of the proceedings of the committee and of the organization of the party.

Very truly yours,

C. A. YOUNG, *Chairman.*

Prof. O. C. MARSH,
*President of the National Academy of Sciences.*




Frontispiece: Bird's-eye View of Caroline Island.

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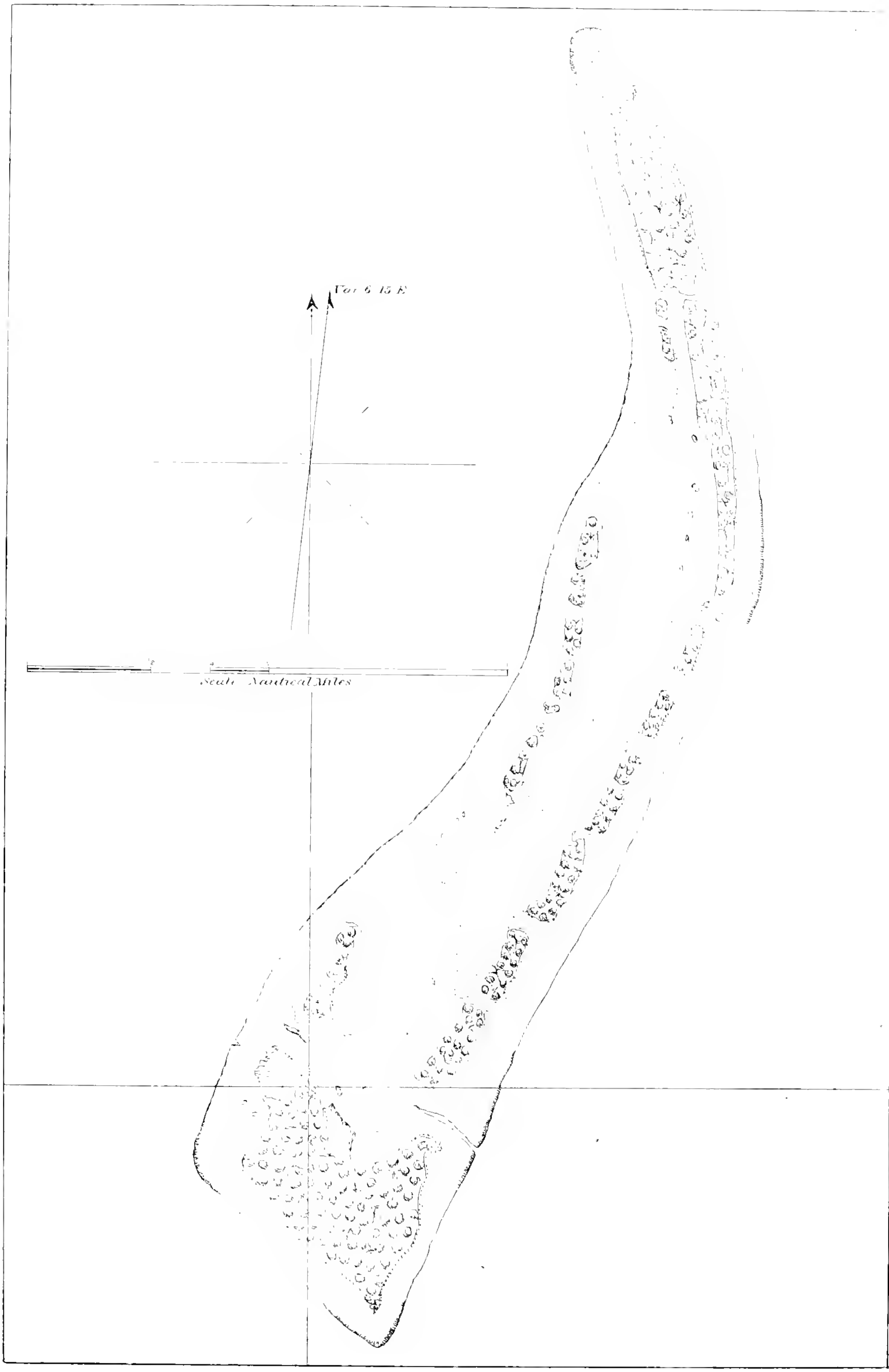
Fig. 2.

GENERAL CHART OF CAROLINE ISLANDS.



# SOLAR ECLIPSE, MAY 6, 1883.

## INTRODUCTION.

By Prof. C. A. Young.

The unusual duration of the total eclipse of May, 1883, early attracted the attention of astronomers; but an examination of its track showed that it would not be visible at any well-known or easily accessible stations, and no preparations were therefore made to secure observations. In May, 1882, Mr. CHARLES H. ROCKWELL, of Tarrytown, N. Y., while in the Sandwich Islands for the purpose of observing the transit of Mercury, learned that there are two small islands lying almost exactly on the central line of the eclipse, and he determined to endeavor to have an eclipse expedition organized from the United States. He presented the matter before the Montreal meeting of the A. A. A. S. in August, but various circumstances prevented any definite action of that body. In November, 1882, the writer, at Mr. ROCKWELL'S suggestion, brought the subject before the National Academy of Sciences at their New York meeting, and a committee was appointed, consisting of Messrs. COFFIN, H. DRAPER, A. HALL, HILGARD, NEWCOMB, and H. A. NEWTON, with the writer as chairman, to commend the project of an eclipse expedition to some suitably situated island in the Pacific, "to persons interested in the advancement of science, and to the Navy Department of the United States for such aid and facilities as can be best afforded." Subsequently, on the death of Dr. DRAPER, Professor LANGLEY was appointed in his place, and Mr. C. S. PEIRCE was added to the committee. Mr. ROCKWELL also, though not a member of the Academy, was invited to join the committee, as having been the real originator of the project. Mr. COFFIN was chosen secretary, and to his energy and wise and skillful management our success in organizing and sending out the expedition is due.

It was at first proposed to raise the necessary funds for the expedition by private subscription, and Mr. ROCKWELL was put in charge of the matter. His own illness, the lamented death of Dr. DRAPER, and other untoward circumstances combined, however, to prevent his success, and on January 24 he reported that this plan must be abandoned. It was at once decided to apply to the Government. Early in February the committee presented the matter to the honorable Secretary of the Navy, representing that the Department could greatly aid the undertaking by detailing a ship of the Pacific squadron for the transportation of the party, and by giving the use of certain astronomical instruments under its control. The application met with a prompt and favorable response.

A meeting of the committee was held in Washington on February 15, at which plans for the expedition were discussed and settled, and the chairman and secretary were directed to address further communications to the Secretary of the Navy to arrange plans of operation to secure the services of suitable observers, to prepare necessary instructions, and, in short, to do whatever was needful and in their power to secure the object desired. Prof. E. S. HOLDEN, director of the Washburn Observatory, Madison, Wisconsin, was selected as chief of the party and its scientific director, and Mr. ROCKWELL as the disbursing and business agent.

A memorial was presented to Congress asking for an appropriation of $5,000 to defray the necessary expenses of the party. This application was heartily indorsed and supported by the honorable Secretary of the Navy and by all the members of Congress who are interested in scientific matters; and the grant was obtained without any serious opposition. This appropriation, however, though practically secured, was not available in season for the departure of the expedition, and, to meet the difficulty, the trustees of the BACHE fund of the National Academy advanced $3,500, to be repaid from the Congressional appropriation.

Subsequently the Academy itself, on the recommendation of the trustees, authorized an appropriation of $500 from the income of the WATSON fund for observations of this eclipse.

The party left New York on March 2, in the Pacific Mail steamer bound for Callao via Panama. At Callao they found the U. S. S. *Hartford* in readiness, and sailed at once for Caroline Island, arriving there on April 21. At Panama, in accordance with certain arrangements which had been made by cable between the Solar Physics Committee of the British Royal Society and our own committee, they were joined by Messrs. LAWRANCE and WOODS, who were especially charged by the British committee with photographic observations. A French expedition, under Mr. JANSSEN, also came to Caroline Island a few days after the arrival of our own party.

The history of the expedition and an account of the work accomplished are fully given in the following reports of Professor HOLDEN and his associates.

We are under great obligations to all these gentlemen, Professor HOLDEN, Professor HASTINGS, of Baltimore, Mr. ROCKWELL (who, in addition to scientific work, had charge of the disbursements and business matters of the expedition), Ensign (now Professor) S. J. BROWN, U .S. N., Mr. E. D. PRESTON, of the United States Coast and Geodetic Survey, and Mr. W. UPTON, of the Signal Service, United States Army, for the zeal and intelligence with which each accomplished the work assigned him: also to the institutions with which they were severally connected for granting to these observers prolonged leave of absence, and, except in the case of Mr. UPTON, continuing their salaries without diminution.

Our acknowledgments are specially due to Hon. W. E. CHANDLER, Secretary of the Navy, for continual interest and effective aid, without which we should have been unable to accomplish anything; also to the Superintendent of the United States Naval Observatory for the loan of instruments; to the Superintendent of the United States Coast and Geodetic Survey, and to Commodore J. G. WALKER, Chief of the Bureau of Navigation. Applications to the Secretaries of State and of the Treasury for certain assistance from their Departments were cordially and promptly granted, and we take the opportunity to express our thanks.

The tribute paid by Professor HOLDEN, in his report, to Captain C. C. CARPENTER, commanding the *Hartford*, and to his officers and crew, is cordially indorsed, as well as his appreciation of the services of those officers who took part in the observations of the eclipse.

The committee held a final meeting in Washington on October 23. The reports of Professor HOLDEN and his associates (excepting Professor HASTINGS) were presented, discussed, and put in proper form for presentation to the Academy at its November meeting in New Haven.

The chairman was requested to prepare an introduction to the reports, and it is in obedience to this request that the preceding pages have been prepared. It would be improper to fail to state that the writer is indebted to the secretary, Mr. COFFIN, for nearly all the substance and much of the form of what he has written.

The reports of Professor HOLDEN and his associates speak for themselves, and will certainly be found valuable and interesting. The question of an intra-Mercurial planet would appear to be definitely settled in the negative by Professor HOLDEN'S work. Professor HASTINGS'S observations, and his discussion of them, unquestionably open (if they do not also close) an important and interesting inquiry as to the correctness of certain generally received views as to the nature of the corona. The observations of Mr. UPTON are extremely valuable, and the same is true of nearly all the others, throwing new light, as they do, not only upon the strictly astronomical problems of the eclipse, but upon the meteorology and natural history of a comparatively unknown region.

PRINCETON, *December*, 1883.

# REPORT

OF THE

# OPERATIONS OF AMERICAN EXPEDITION TO OBSERVE THE TOTAL ECLIPSE, 1883, MAY 6, AT CAROLINE ISLAND, SOUTH PACIFIC OCEAN.

To Prof. C. A. YOUNG,

*Chairman of the Eclipse Committee of the National Academy of Sciences:*

MY DEAR PROFESSOR YOUNG: It gives me great pleasure to address to you my report of the Total Solar Eclipse of May 6, 1883, together with the reports of the other members of the American expedition and with a memorandum from the chief of the English photographic party which accompanied us. We had all hoped and expected to have you for our director in this expedition, and you will allow me to express my regret that unforeseen circumstances prevented this.

My first official connection with the expedition dates from my reception of the following letter of instructions, under which I acted:

WASHINGTON, D. C., *February* 28, 1883.

Prof. E. S. HOLDEN:

DEAR SIR: The Committee of the National Academy of Sciences on the Solar Eclipse of May 6, 1883, has selected you as the Chief and Scientific Director of the party organized under its direction for observations of the various phenomena on that occasion; to prescribe and arrange the work of each member, except so far as it may have been laid down by the committee in special instructions to any one, or may have been assigned to the representative of the United States Coast and Geodetic Survey. The names of the party and the letter of instructions to each have been communicated to you. This leaves the eclipse work in your hands, but the committee desires that every facility which can be obtained, be afforded Mr. PRESTON for his gravity determinations.

As for your own special work, the search for intra-mercurial planets, the programme sketched

## ERRATA.

Page 22, line 11.—The statement in line 11 is derived from a letter of Mr. [illegible] and is undoubtedly correct. The fifty or one hundred people spoken of on page 21, line 25, were probably imported workmen.

Page 24, Fig. 6.—By an error, which was discovered too late to be corrected, the shadows of the foliage in Fig. 6 are those of a northern forest. They should be far less marked and regular, and the trunks of the trees should all be brilliantly lighted. With this exception, the cut shows the character of the growth admirably.

Page 31, line 5 from bottom.—*For* 27·8 *read* 27·85.

Page 33, line 10 from bottom.—*For* discordancies *read* discordances.

Page 43, title of cut.—*For* Fig. 15 *read* Fig. 13.

Page 56, title of cut.—*For* Fig. 16 *read* Fig. 14.

Page 57, title of cut.—*For* Fig. 17 *read* Fig. 15.

Page 58, title of cut.—*For* Fig. 18 *read* Fig. 16.

Page 67, title of cut.—*For* Fig. 10 *read* Fig. 17.

Page 80, title of cut.—*For* Fig. 13 *read* Fig. 18.

Page 86, title of cut.—*For* Fig. 14 *read* Fig. 19.

Page 113, line 11.—*For* JASSEN *read* JANSSEN.

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As for your own special work, the search for intra-mercurial planets, the programme sketched in your letter to me of February 6, marks out distinctly what you should aim at accomplishing.

I send you letters to Admiral HUGHES, commanding United States naval forces, Callao, and to Captains CARPENTER and FYFFE, commanding U. S. S. *Hartford* and *Pensacola*, one of which will be detailed to convey the party to their destination. They are communicated for your information. Mr. ROCKWELL will act under your direction as to the expenditure of funds, and it is desirable to have your certificate to his vouchers after your leaving New York.

It is expected that you leave New York in the Pacific Mail steamer of March 2, for Panama and Callao. On arrival at the latter place please report to Admiral HUGHES for conveyance to Caroline Island, as indicated in directions given him by the Navy Department.

I wish you a pleasant voyage and full success in the enterprise intrusted to you.

I am, very truly, yours,

J. H. C. COFFIN,

*Secretary of Committee of the National Academy of Sciences.*

As our voyage and our subsequent stay on Caroline Island were something out of the run of common experience, you will allow me to give some details concerning them, which usually do not form a part of a scientific report.

## II.—ORGANIZATION OF THE EXPEDITION.

The American party consisted of EDWARD S. HOLDEN, director of the Washburn Observatory, Madison, Wis.; CHARLES S. HASTINGS, professor of physics in the Johns Hopkins University, Baltimore, Md.; CHARLES H. ROCKWELL, Tarrytown, N. Y.; E. D. PRESTON, aid United States Coast and Geodetic Survey, Washington, D. C.; WINSLOW UPTON, United States Signal Office, Washington, D. C.; Ensign S. J. BROWN, U. S. N., United States Naval Observatory, Washington, D. C.

The original six members of the party were joined on April 20 by four volunteer observers, all officers of the U. S. S. *Hartford*. These were, Lieut. E. F. QUALTROUGH, U. S. N.; Passed Assistant Surgeon W. S. DIXON, U. S. N.; Midshipman W. B. FLETCHER, U. S. N.; Midshipman J. G. DOYLE, U. S. N.

On March 11, the party was strengthened by the joining (at Colon) of the two English gentlemen who were sent out by the Royal Society of London to make photographic observations of the eclipse, under instructions from J. NORMAN LOCKYER, Esq., F. R. S., and Captain W. DE W. ABNEY, Royal Engineers, of the Science and Art Department of the South Kensington Museum. These were H. A. LAWRENCE, London, England; C. RAY WOODS, London, England.

During our stay on Caroline Island (April 21 to May 9), the following petty officers and men of the *Hartford* remained with us and rendered very intelligent assistance: HORACE YEWELL, seaman-gunner; CHARLES EMMS, carpenter's mate; PETER MURPHY, carpenter; JOHN SMITH seaman; J. C. HAROLD, seaman; C. A. PERKINS, ordinary seaman (apprentice); JAMES MCKENNA, ordinary seaman (apprentice); PETER BURNS, steward; THOMAS G. BROOKS, assistant steward; MORTIMER C. SPENCE, landsman.

Our party on the island consisted of twenty-two persons in all.

## III.—JOURNEY FROM NEW YORK TO CAROLINE ISLAND AND RETURN.

(New York to Colon, 1,989 miles; Colon to Callao, 1,722 miles; Callao to Caroline Island, 4,324 miles; Caroline Island to Honolulu, 2,100 miles; and from Honolulu to San Francisco, 2,092 miles.)

BY PROF. E. S. HOLDEN.

The six members of the American party sailed from New York March 2, 1883, on the Pacific Mail steamship *Acapulco* (Capt. W. SHACKFORD), and arrived at Colon March 11, after touching at Castle Island, March 7, to send off a mail. At Colon the expedition was joined by the English photographic party. As the steamer on the west coast of South America did not leave until the evening of March 12, the American party remained in Colon till the morning of that day, and went from thence to Panama. Both in Colon and in Panama we were indebted to the courtesy of Capt. J. M. DOW, of Panama, for expediting our movements and for personal favors.

At Panama I telegraphed to the United States and also to the admiral commanding the Pacific squadron. Through the kindness of my friend CLARENCE CARY, Esq., of New York, I found that all our telegrams over the lines along the west coast of South America and through to the United States were sent free of charge. Early in the morning of March 13 we sailed on the P. S. Navigation Company's steamer *Bolivia* (Captain FERGUSON), for Callao, stopping at Buenaventura (March 14), Tumaco (March 15), Guayaquil (March 17), Payta (March 18), and arrived at Callao, March 20. I at once called on Capt. C. C. CARPENTER, commanding the *Hartford*, from whom I learned that he would be ready to sail on March 22. March 21 was spent in Lima, and on March 22 the *Hartford* left Callao for Caroline Island, a distance of 4,324 miles.

On the twenty-third day out from Callao we sighted one of the islands of the Marquesas group, and at 8 a. m. of April 20 Caroline Island was seen as a low green streak on the horizon. We had come 4,324 miles in twenty-nine days, mostly under sail (an average of 149 miles per day), without seeing a single sail or any land, except Magdalena Island of the Marquesas, which we had gone out of our course to sight. I cannot refrain from quoting here DARWIN's entry in his *Journal of a Voyage in the Beagle*, under date of December 19, 1835:

"We may now consider that we have nearly crossed the Pacific. It is necessary to sail over this great ocean to comprehend its immensity. Moving quickly onwards for weeks together, we meet with nothing but the same blue, profoundly deep ocean. Even within the archipelagoes the islands are mere specks and far distant one from the other. Accustomed to look at maps drawn on a small scale, where dots, shading, and names are crowded together, we do not rightly judge how infinitely small the proportion of dry land is to the water of this vast expanse."

## STAY ON CAROLINE ISLAND.

(From April 21 to May 9.)

It must be remembered that we knew absolutely nothing of Caroline Island, except that it had been inhabited in 1874 by at least one white man and some thirty natives. The boat landing was known to be somewhere on the southwestern side, and an "entrance to the lagoon" was spoken of on the eastern side. The *Hartford* approached the island from this side, and from end to end there was nothing to be seen but a line of heavy breakers, then a strip of white beach, and above this a growth of trees, the highest of which were cocoa palms. Finally, in among these, was seen the gable roof of a European house, but no inhabitants. Coasting round the island, everywhere surrounded by high surf, the *Hartford* came opposite the place where the boat landing was reported, and the whale-boat was lowered and Lieutenant QUALTROUGH sent in her to land if possible. It seems all very simple now, after Caroline Island, its reefs, its lagoon, and its landing are as familiar to us as the beaches of New England; but at the time it was all quite strange and new. The advent of a man and a dog on the reef was an event. It seemed to settle one thing, at least, and that was that we should find some assistance in landing. But the native disappeared and Lieutenant QUALTROUGH was left to find his own way among the breakers, which he did in a capital manner.

The ocean reef forms a solid wall all round the islands, except at one narrow and crooked entrance, just wide enough for a boat and oars, and through this entrance each boat must come or be broken into bits against the steep face of the coral wall. The whale-boat returned shortly with the news that there were four native men, one woman, and two children on the islands, that two frame houses were standing, and that we could land at once. On the 20th of April the first of our boxes were sent ashore. The boats were loaded alongside and rowed to the entrance of the narrow passage. This was entered on the top of a wave and the boat was skillfully steered by the cockswain through its windings. As soon as the bow came over the flat surface of the reef the crew jumped out and hauled it up into the shallow water covering the whole surface of the reef. At high water this ocean reef was covered to a depth of about 30 inches and at low water to about 10 inches.

The boxes were then lifted from the boat and transported by carrying parties to the high-water mark—a distance of 1,400 feet. This transport had to be made over the rugged surface of the ocean reef and through water varying in depth from 1 to 3 feet, as I have said. From high-water mark other carrying parties transported the boxes along the beach of the lagoon and across the island to the site of our observatories (some 1,300 feet further), which had been selected by Dr. HASTINGS and myself. On board the *Hartford* I had prepared a plan of the proposed camp; the position of each observatory was fixed on the ground by a stake, and to this stake all the boxes of each instrument were brought. In this way all proceeded in an orderly manner. By the evening of the 21st all the boxes and baggage of the expedition were landed, as well as bricks, cement, lumber, etc., for the observatories. The entire party slept on shore also, and I shall never forget the quiet rest of that cool night after the intensely hot day of active work.

Our hammocks were slung on the wide veranda of one of the houses close to the beach of the mirror-like lagoon. The wind was cool and fresh as it blew through a break between two of the islands and directly from the open sea, the monotonous roar of whose surf was incessantly heard. The nearly full moon was overhead and the long fronds of the cocoa palms made grotesque shadows on the level ground. Occasionally there would be heard the shrill cry of some sea-bird flying over, and other than this and the roar of the breakers there was nothing to disturb the quiet and rest which came as a fitting conclusion to our restless month at sea.

During the 22d of April the *Hartford* remained by the island, and a force of carpenters and bricklayers proceeded rapidly with the construction of our observatories. By night time the observatories belonging to myself, Dr. HASTINGS, and Mr. PRESTON were up, and piers of brick or wood completed. The brick piers of the English party were well under way and were completed on the 23d by Mr. WOODS, who thus added a new profession to his former acquirements.

The *Hartford* sailed at 6 p. m. of the 22d for Tahiti and some of us went to the ocean reef to see her off. Besides her lights, we saw those of *L'Eclaireur*, the man-of-war which was bringing the French eclipse expedition. Early on the morning of the 23d I met the maître d'equipage of the *Eclaireur* on the reef and gave him such information as to the landing, etc., as I was sure would be of use. Shortly after this the French party came on shore for the day, and the morning was spent in aiding them to select a site for their observatories, etc.

This party consisted of M. JANSSEN, director of the Observatory of Astronomical Physics of Meudon; M. TROUVELOT, assistant at the Meudon Observatory; M. PASTEUR, photographer of the Meudon Observatory. These gentlemen were accompanied by M. TACCHINI, director of the Observatory of the Roman College and M. PALISA, astronomer of the Imperial Observatory of Vienna. Besides these astronomers there were seventeen of the crew of *L'Eclaireur* left on shore, making the French party twenty-two in number. Thus the total population of the island was fifty-one in all, including natives.

Our relations with the gentlemen of the French expedition were throughout of the most cordial character, and so far as our researches lay in the same direction, we worked together to a common end. It was a pleasure to us to be able to extend to them what aid was possible, and to receive the same in return.

During the remaining days of April everything was making progress towards complete readiness for observations of the eclipse. The observatory of Dr. HASTINGS and my own were completed by April 27, and each of us used a six-inch equatorial for some hours each night in an examination of the southern sky. During the course of this we detected some new doubles and red stars, a list of which is given later. The vision was not exceptionally good, and comparatively few hours were given to telescopic work, owing to the impossibility of obtaining a quiet sleep during the day. Still twenty-three double stars were found. This shows that if a suitable telescope were to be used in a favorable place in the southern hemisphere, as Quito or Santiago for example, a great number of new objects could be catalogued in a comparatively short time. It appears to me that this expedition is worth making. Every day during May a rehearsal for the eclipse observations was gone through with, and two days before May 6 everything was in complete readiness.

On the morning of May 6 there were three rain showers and several persistent banks of clouds. The sky was clear at first contact (about $10^h$ $3^m$ local mean time), cloudy at intervals till near totality; clear during totality, except slight haze during the first minute of totality; cloudy a few minutes after third contact, and finally clear at fourth contract.

The observations of the various parties may be considered to have been successful; but the success was owing to the apparent accident of the dissipation of a local cloud. I am more than ever convinced that my conclusion to go to Flint Island, had I found the French party occupying Caroline Island, was a sound one.

Immediately after the eclipse we commenced preparations for departure. These occupied May 7 and May 8. Captain CARPENTER had promised to return from Tahiti with the *Hartford* by the morning of May 9, but we were pleased to see his arrival at 4 p. m. of the 8th.

By hard work all was packed and delivered on the *Hartford* by 4 p. m. of May 9, and at 5 p. m. the *Hartford* with the expedition on board took her departure for the Sandwich Islands.

We left Caroline Island with mingled feelings of pleasure and regret. Each one of us had at least some one thing left to do or to see, and yet it was a pleasure to leave the place where our mission had been accomplished and to meet our friends in the ship who were endeared to us by that intimacy which sea-life induces.

This is the place to say one word in regard to the outfit of stores and provisions which was provided in New York and Callao by Mr. ROCKWELL and myself. All the advice we received in the United States from various persons who might have been supposed to know, was to the effect that we had better not encumber ourselves with stores, etc., from New York; that the markets of Callao and the resources of a man-of-war would amply supply our needs. Acting contrary to this advice we took a large quantity of provisions from New York, together with the canvas, tents, etc. which we were told could be obtained from the man-of-war. At Callao an additional supply of provisions was purchased, together with the bricks, cement, and lumber which were found to be necessary for the English expedition and our own. The stock of provisions and stores proved to be exactly what we wanted, and we were enabled to support the twelve men of the party on Caroline Island without trouble and to provide a sufficient though primitive *cuisine*. Our only mistake was in not purchasing *all* our provisions and tools in New York, and I have given a brief account of our preparations in this direction, in order to say to other expeditions similar to our own that they will do well to buy all their outfit in New York and pay the freight to the point of destination cheerfully.

I have to express the thanks of the expedition to the honorable Secretary of War, and to my friend Col. H. C. HODGES, Quartermaster's Department, for the loan of three tents, which were of great service to us.

## JOURNEY FROM CAROLINE ISLAND TO THE UNITED STATES.

From Caroline Island the *Hartford* proceeded directly to the Hawaiian Islands under sail, and on May 24 we were anchored in the beautiful bay of Hilo. From Hilo a party from the ship visited the volcano of Kilauea, which we were fortunate enough to find in a very active state. Leaving

Hilo on May 29, we arrived at Honolulu the next day. Here Mr. PRESTON and Mr. BROWN left the party in order to undertake pendulum observations on the island of Maui. On the evening of June 3 the rest of the party embarked on Pacific Mail steamship *Zealandia* (Captain WEBBER) and after a disagreeable passage arrived at San Francisco on June 11.

We had been absent from the United States for one hundred and one days, during which we had traveled some 1,500 miles; seventy days had been passed at sea. We had undertaken the expedition with a willingness to undergo any hardships or discomforts for the sake of the astronomical opportunity, but the difficulties vanished as we saw them nearer. Not a mishap of any kind occurred to interfere with the success of our work, and the entire voyage and the stay on the island was a beautiful surprise to us.

Fifty days of our journey were spent on the U. S. S. *Hartford*, and it is a pleasure for me to return the thanks of the expedition to the officers and men of this vessel for their constant and thoughtful kindness and willingness. We have especially to thank Captain CARPENTER and Lieut. Commander EDWIN WHITE for their promptness in landing our bulky cases under rather exceptional difficulties. Four of the officers of the *Hartford* volunteered to aid us in our observations on Caroline Island, and by the courtesy of Captain CARPENTER they were detailed for the service. Their reports follow in order, and they will show how intelligent and valuable assistance was given. To these gentlemen, Lieutenant QUALTROUGH, Dr. DIXON, Midshipmen FLETCHER and DOYLE, we desire to make this formal tender of our sincere thanks.

It should appear that while Congress and the National Academy appropriated an adequate sum for our current expenses, we still owe to the Navy an aid at least equal. We had the intelligent assistance of four trained observers on the island and the willing aid of the officers and crew of a large war vessel, and without these our difficulties and expenses would have been greatly and seriously increased.

## IV.—CAROLINE ISLAND.

### § 1. HISTORY.—BY PROF. E. S. HOLDEN.

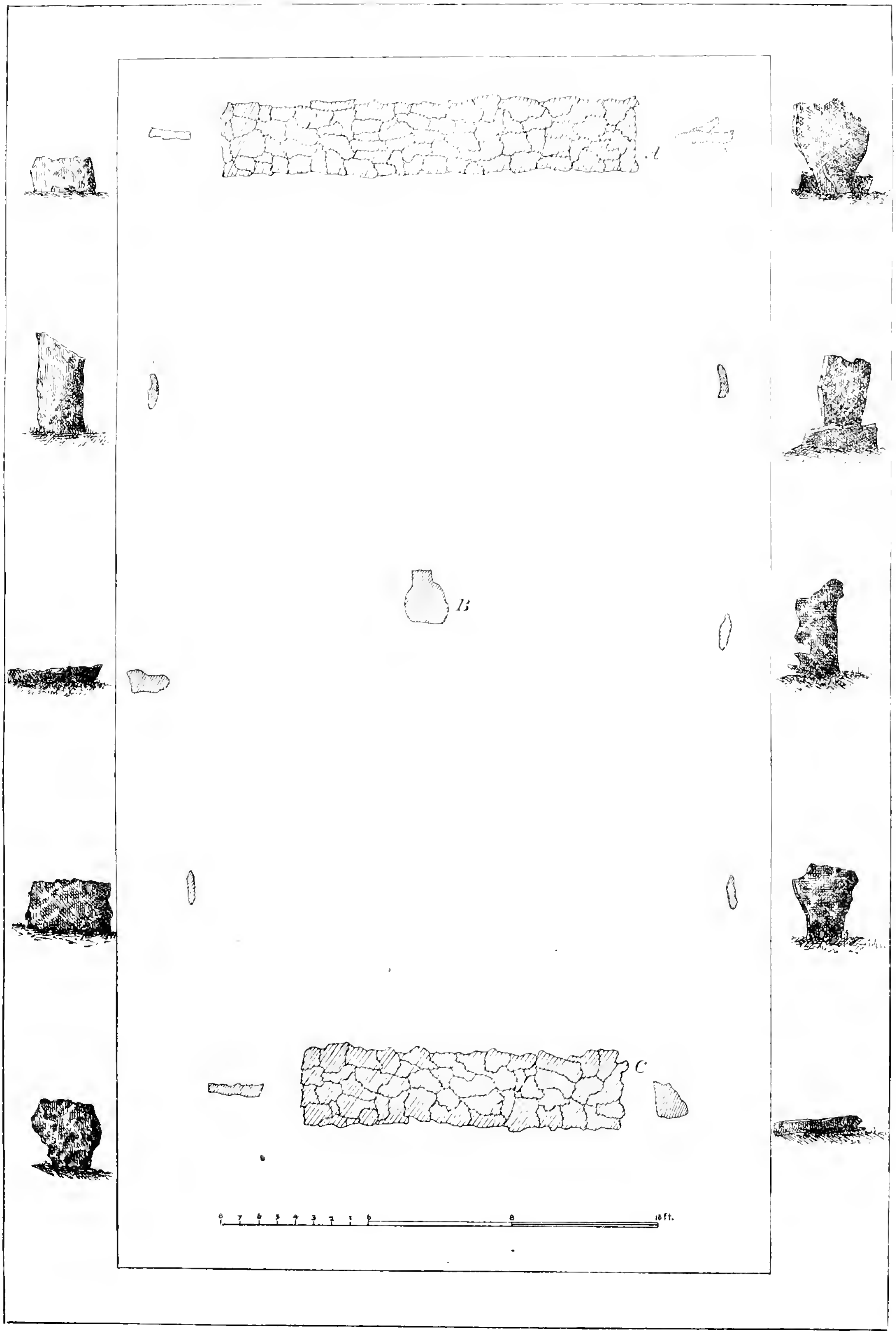
The sum of our knowledge of Caroline Island, before the arrival of the Eclipse Expedition, was given in the following extract from FINDLAY'S South Pacific Directory (1877, page 742):

"Caroline or Thornton Island, is 7 to 8 miles long, N.NE. and S.SW., and from 2 to 3 miles wide, well covered with cocoanut and other trees, of tolerable height, which render it visible at a distance of 16 to 20 miles. It consists of many islets of various sizes, encircling a lagoon. The reef on the windward side breaks, except at the NE. point, to the distance of a mile from the south point of the island. This reef sends out two branches to a distance of 1½ miles—one toward the SE., the other toward the SW. and is consequently dangerous to approach at night. The reef is close to the islets on the west side, and no breakers were seen on the NW. point. There is no anchorage, but a landing (not always safe) may be effected on the north side of the SW. bifurcation, described above and near the spot where the English flag is hoisted on a mast. There are about thirty inhabitants and the resident European is Mr. BROWN. It was taken possession of by Captain NARES, H. M. S. *Reindeer*, for the English, and its latest assigned position is lat. 9° 54′ S., long. 150° 6′ W."

From various hydrographic notices we also learned that Caroline Island was first seen by Captain BOUGHTON in 1795. He assigned the position long. 150° 25′ W., and lat. 9° 57′ S., and he gave it the name it now bears. At one time it was called *Thornton* Island. It was visited in 1870 by Lieutenant CHAUVINIÈRE, of the French transport *Somme*, and in 1868 by Captain NARES, R. N., who took possession of it for the British. The chief occupation of the inhabitants, who numbered

**Fig. 3.**

MARÆ, OR NATIVE BURIAL PLACE.



27 in 1868, was raising stock, pigs, poultry, and collecting fish for salting, and also planting cocoanut trees for oil. About 1878 guano was exported from the island.

The foregoing comprises the entire history of the island. I have applied by letter to every person who might be supposed to know anything of the early history of the island, even to the secretaries of the missionary societies in London and New York, without obtaining any information of value. I addressed letters to various gentlemen who were familiar with the islands in the South Pacific, asking for such information as they had on the history, the aboriginal population, &c., of Caroline Island. Among the replies I have received is one from a gentleman resident on Raroonga, which is given below:

"RAROTONGA, *September* 21, 1883.

"SIR: Your note to the Bishop of Tahiti has been forwarded to me by the Reverend WILLIAM WYATT GILL, of the London Missionary Society. I will give you with pleasure what I have heard concerning Caroline Island, from good authorities—the Messrs. BROWN Brothers, the former owners of the island. Some years ago, I had a conversation with these gentlemen, and they told me that in seeking for guano, they came upon a grave, which made them interested. They sought farther and found others, numbering altogether fifty. In the graves they found stone axes, and highly polished green stones, such as are used by the Maoris of New Zealand, and spears of the same description. The graves had a few stones placed around them.

"Messrs. BROWN & Brothers planted the cocoanut trees on the island. It must have been ten or fifteen years afterward that the island was leased to Mr. ARUNDELL of the firm of HOULDER Bros. & Co. Although I have been several months on Flint Island in the said company's employ, I have never seen Caroline Island, but Mr. ARUNDELL told me he had found axes, fancy stones, etc., on the island.

"Messrs. BROWN & Brothers told me they thought the number of the inhabitants at the time they took possession* could not have been over fifty or a hundred people. It seemed as if there had been a storm or hurricane at some short period previous, which had desolated the place. The occupation of the natives, if they had any, would be fishing or fighting, or anything they could possibly do in such a small island.

* * * * * * *

"J. MORTIMER SALMON."

In a note from the Rev. W. WYATT GILL, he says that he does not believe the island had an aboriginal population, which is in all likelihood the case.

In a letter dated Auckland, New Zealand, August 6, 1883, Mr. ARUNDELL, the present lessee of the island, says:

"I regret that I have not many facts in the history of the island to communicate to you. It was taken possession of by Her Britannic Majesty on July 9, 1868, and the English flag hoisted by Commodore (now Sir GEORGE) NARES in H. M. S. *Reindeer*. We became Crown tenants in 1872, and have remained in possession ever since, carrying on guano operations there; and in 1881 I took the affair up individually and apart from my firm, and commenced the planting of cocoanuts there, as also on the neighboring Flint Island. I presume you took photographs of the island, but if not, and they should be of any use or interest, I could send you some of the houses, scenery, etc., which we took with our own camera a few years back.

"There are some curious old marais, *i. e.*, burying or sacrificial places. Probably my natives did not show them to you. Of these I have photographs and plans, and should you care about them, I would forward them also."

* * * * * * *

* This must have been between the years 1865-1872.—E. S. H.

The drawing from which Figure 3 is engraved was made by GEORGE W. ROBERTSON, Esq., of Liverpool, and is accurate. Mr. ARUNDELL describes it very briefly in a letter of January 1st, 1881. The plan gives the disposition of the various masses about the central space. The figures in the margins are the elevations of the ten smaller blocks shown in the plan on the borders of the inclosure. The two walls at the ends are *not* represented in plan, but are revolved 90° so as to appear in elevation. With this explanation the figure can be understood.

The material of the blocks and walls is coral and coral conglomerate. Mr. ARUNDELL opened cairn C without finding any trace of bones, ashes, or of any human remains. They are situated on the western side of the most northern islet, and there are a few smaller ones on the south point of the longest islet on the eastern side. They must have been built by a native population, but no natives were known to inhabit the island at its first occupation by the whites.

## §2. DESCRIPTION OF THE ISLAND.

BY PROF. E. S. HOLDEN; AND LIEUT. E. F. QUALTROUGH, U. S. N.

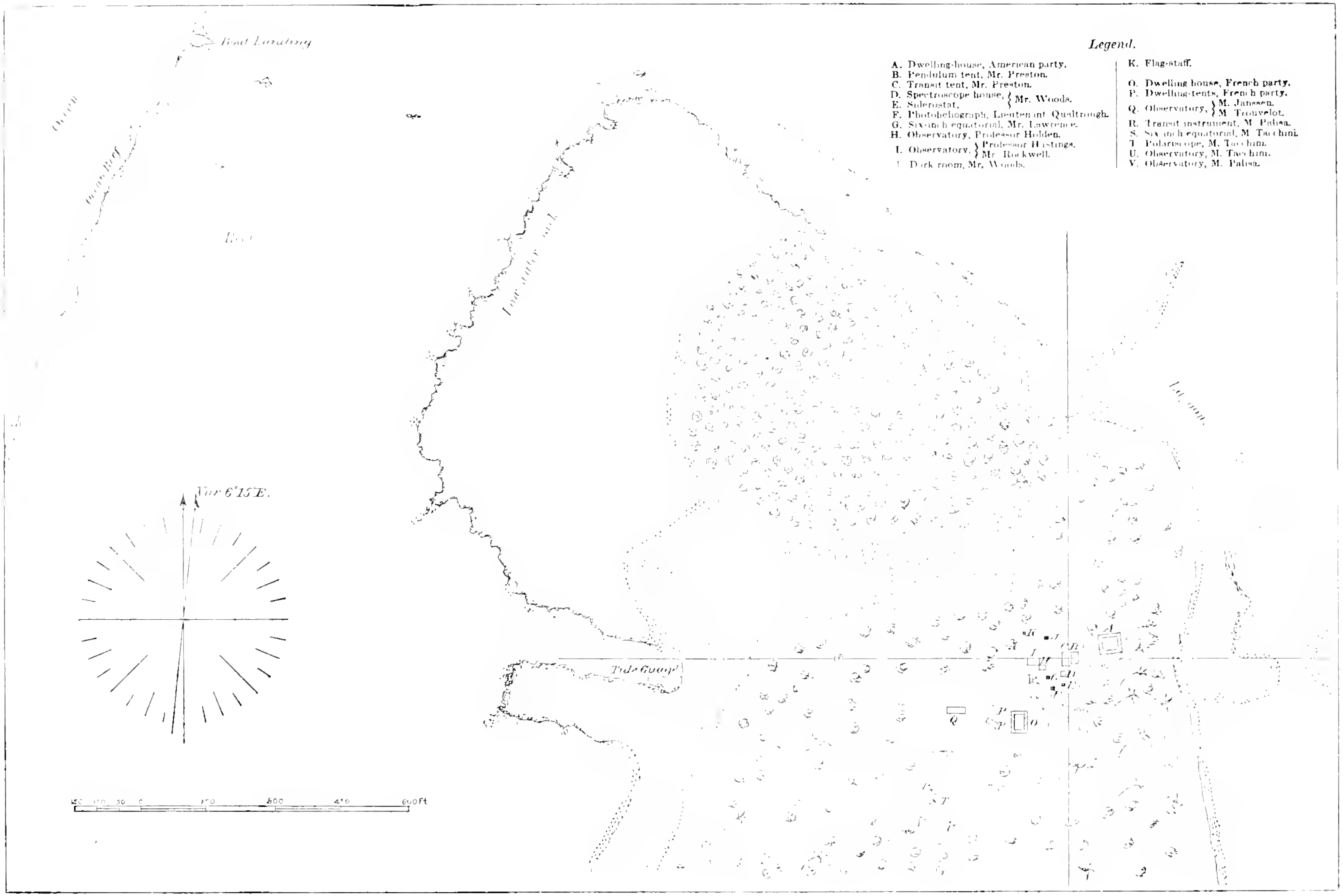
Our own observations and the careful survey of the island which was made by Lieutenant QUALTROUGH and Midshipmen FLETCHER and DOYLE, enable me to give a tolerably accurate description of Caroline Island. I desire, however, before giving the results of our own work to quote from Professor DANA'S *Corals and Coral Islands*, and from DARWIN'S *Voyage of the Beagle*, their accounts of typical coral atolls which they visited. The only changes necessary in their descriptions, to make these apply exactly to our station, are changes in the dimensions of the ocean reefs, the beaches, etc. The general features of a coral atoll are most perfectly and graphically described by them. To understand their accounts, I may say that the general shape of Caroline Island is that of a pear-shaped ring of islets, encircling a lagoon. The islets are based on the ocean reef which DANA calls the *shore platform.*

Between the islets are portions of this platform, which are nearly bare at low water. Inside the ocean reef is the lagoon, which is itself filled with reefs of corals. Professor DANA says: "The *shore platform* is from one to three hundred feet in width, and has the general features of a half-submerged outer reef. Its peculiarities arise solely from the accumulations which have changed the reef into an island. Much of it is commonly bare at low tide, though there are places where it is always covered with a few inches or a foot of water; and the elevated [outer] edge, the only part exposed, often seems like an embankment preventing the water from running off. The tides, as they rise, cover it with water throughout and bear over it coral fragments and sand, comminuted shells, and other animal remains, to add them to the beach.

"The heavier seas transport larger fragments; and at the foot of the beach there is often a deposit of blocks of coral, or coral rock, which low tide commonly leaves standing in a few inches of water. On moving these masses, which generally rest on their projecting angles, and have an open space beneath, the waters at once become alive with fish, shrimps and crabs, escaping from their disturbed shelter; and beneath appear various actiniæ or living flowers, the spiny echini and sluggish *beche de mer*, while swarms of shells, having a soldier crab for their tenant, walk off with unusual life and stateliness. Moreover, delicate corallines, ascidiæ, and sponges, tint with lively shades of red, green, and pink the under surface of the block of coral which had formed the roof of the little grotto. The beach consists of coral pebbles or sand, with some worn shells, and occasionally the exuviæ of crabs and bones of fishes. Owing to its whiteness, and the contrast it affords to the massy verdure above, it is a remarkable feature in the distant view of these islands.

Fig. 4.

DETAILED CHART OF THE SOUTHERN ISLET OF CAROLINE ISLANDS.



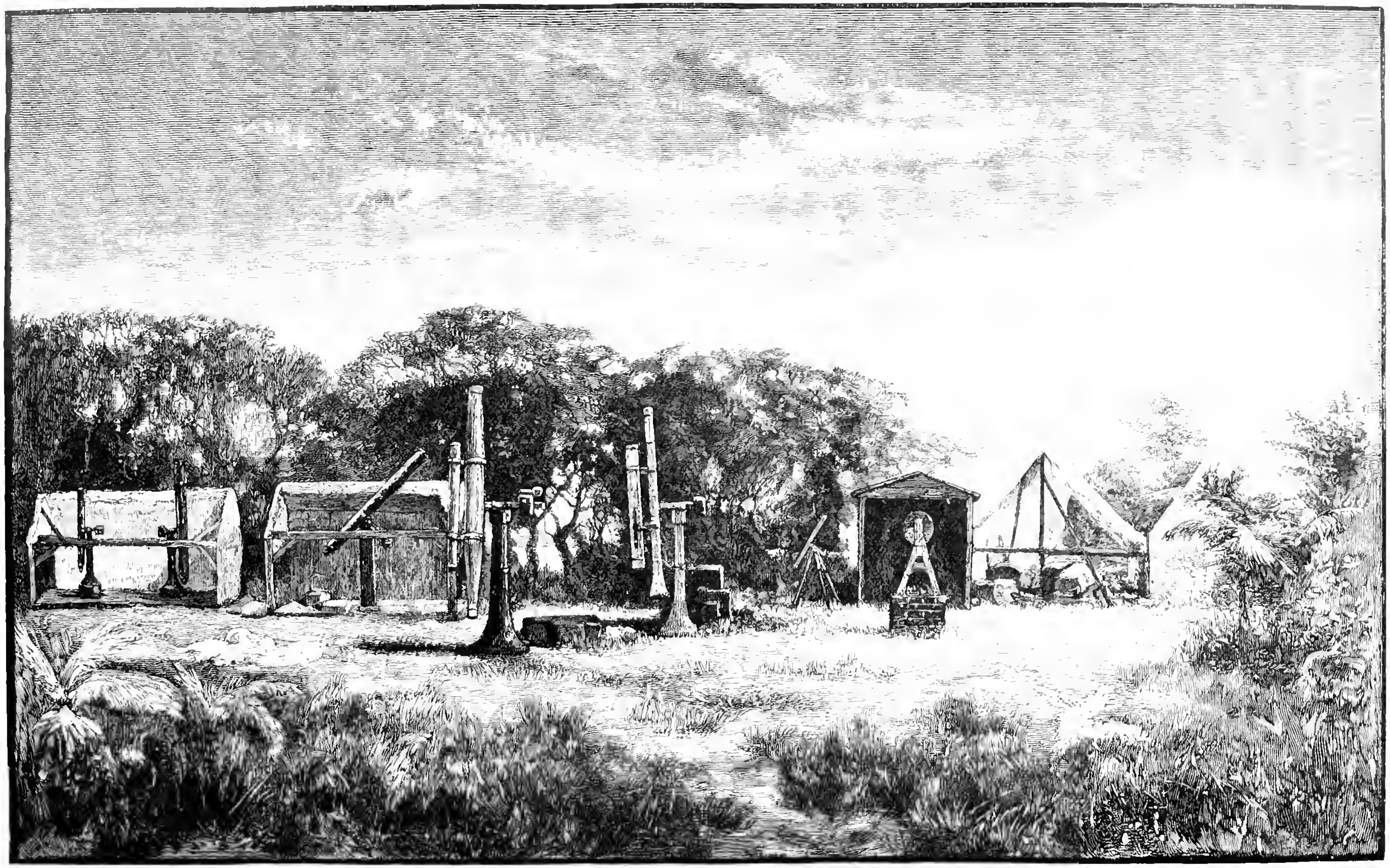


Fig. 5.—General View of the Astronomical Station at Caroline Island.

"The *emerged land* beyond the beach in its last stage stands 6 to 10 feet out of water. The surface consists of coral sand, more or less discolored by vegetable or animal decomposition. Scattered among the trees stand, still uncovered, many of the larger blocks of coral, with their usual rough angular features and blackened surface. There is but little depth of coral soil, although the land may appear buried in the richest foliage. In fact, the soil is scarcely anything but coral sand. It is seldom discolored beyond 4 or 5 inches, and but little of it to this extent. There is no proper vegetable mold, but only a mixture of darker particles with the white grains of coral sand. It is often rather a coral gravel, and below a foot or two it is usually cemented together into a more or less compact coral sand-rock.

"The shore of the lagoon is generally low and gently inclined, yet in the larger islands [as at Caroline Island] there is usually a beach resembling that on the seaward side, though of less extent. A platform of reef-rock, at the same elevation as the shore-platform, sometimes extends out into the lagoon; but it is more common to find it a little submerged, and covered for the most part with growing corals; and, in either case, the bank terminates outward in an abrupt descent, of a few yards or fathoms, to a lower area of growing corals or to a bottom of sand. Still more commonly we meet with a sandy bottom, gradually deepening from the shores, without growing coral. These three varieties of condition are generally found in the same lagoon, characterizing its different parts. The lower area of growing corals slopes outward and ceases when the depth is 10 to 12 fathoms or sooner.

"There are usually currents flowing to leeward through the lagoon, and out, over, or through the leeward reef, the waves with the rising tide dashing over the windward side, and keeping up a large supply, which is greatly increased in times of storms; and this action tends to keep open a leeward channel for the passage of the water."

The various illustrations scattered through this section (which are engraved from photographic prints kindly furnished by the gentlemen of the English expedition) will make this description more clear to those who have not actually seen a coral atoll. They have been redrawn from the prints by Mr. R. N. BROOKE, of Washington, to whom our thanks are due for the care which he brought to his difficult task.

From DARWIN'S *Journal* the following extracts are taken:

"The ring-formed reef of the lagoon island is surmounted in the greater part of its length by linear islets. On entering the lagoon the scene was very curious and rather pretty. Its beauty, however, entirely depended on the brilliancy of the surrounding colors. The shallow, clear and still water of the lagoon, resting in its greater part on white sand, is, when illumined by a vertical sun, of the most vivid green. This brilliant expanse, several miles in width, is on all sides divided, either by a line of snow-white breakers from the dark heaving waters of the ocean, or from the blue vault of heaven by the strips of land, crowned by the level tops of the cocoanut trees. As a white cloud here and there affords a pleasing contrast with the azure sky, so in the lagoon, bands of living coral darken the emerald-green water."

"The next morning after anchoring I went on shore. The strip of dry land is only a few hundred yards in width. On the lagoon side there is a white calcareous beach, the radiation from which under this sultry climate was very oppressive; and on the outer coast, a solid broad plat of coral rock served to break the violence of the open sea. Excepting near the lagoon, where there is some sand, the land is entirely composed of rounded fragments of coral. In such a loose, dry, stony soil, the climate of the intertropical regions alone could produce a vigorous vegetation. On some of the smaller islets nothing could be more elegant than the manner in which the young and full-grown cocoanut trees, without destroying each other's symmetry, were mingled into one wood. A beach of glittering white sand formed a border to these fairy spots."

"The long strips of land forming the linear islets have been raised only to that height to which the surf can throw fragments of coral, and the wind heap up calcareous sand. The solid plat of coral rock on the outside, by its breadth, breaks the first violence of the waves, which otherwise in a day would sweep away these islets and all their productions. The ocean and the land seem here struggling for mastery. Although *terra firma* has obtained a footing the denizens of the water think their claim at least equally good. In every part one meets hermit crabs of more than one species carrying on their backs the shells which they have stolen from the neighboring beach. Overhead numerous gannets, frigate-birds, and terns rest on the trees; and the wood, from the many nests and from the smell of the atmosphere, might be called a sea-rookery. The gannets, sitting on their rude nests, gaze at one with a stupid yet angry air. The noddies, as their name expresses, are silly little creatures. But there is one charming bird; it is a small snow-white tern, which smoothly hovers at the distance of a few feet above one's head, its large black eye scanning, with quiet curiosity, your expression. Little imagination is required to fancy that so light and delicate a body must be tenanted by some wandering fairy spirit."

"The next day I employed myself in examining the very interesting yet simple structure and origin of these islands. The water being unusually smooth, I waded over the outer plat of dead rock as far as the living mounds of coral, on which the swell of the open sea breaks. In some of the gullies and hollows there were beautiful green and other colored fishes, and the form and tints of many of the zoöphytes were admirable. It is excusable to grow enthusiastic over the infinite numbers of organic beings with which the sea of the tropics, so prodigal of life, teems, yet I must confess I think those naturalists who have described, in well-known words, the submarine grottoes decked with a thousand beauties have indulged in rather exuberant language."

"Every single atom, from the least particle to the largest fragment of rock, in this great pile, which, however, is small compared with very many other lagoon islands, bears the stamp of having been subjected to organic arrangement. We feel surprised when travelers tell us of the vast dimensions of the pyramids and other great ruins, but how utterly insignificant are the greatest of these when compared to these mountains of stone accumulated by the agency of various minute and tender animals! This is a wonder which does not at first strike the eye of the body, but, after reflection, the eye of reason."

The foregoing extracts give a complete picture of the typical coral atoll, and, as I have said, we require simply to make a few changes in the dimensions to make them exactly apply to Caroline Island. The frontispiece, which is derived from the survey made at my request, will give the necessary changes at a glance.

To this I add a brief description furnished by Lieutenant QUALTROUGH.

"CAROLINE ISLAND, or chain of islands, is of coral formation of the lagoon type, and in shape is an irregular elongated oval; it is $5\frac{3}{4}$ miles long from NNE. to SSW. and its circumference, measured on the outer or inclosing reef, is approximately 13 miles. The greatest breadth is at the southern end, where it measures $1\frac{1}{8}$ miles, and the average width may be placed at three quarters of a mile.

"The atoll consists of a chain of twenty-five little islets, well covered with trees and shrubbery, the whole forming a quiet scene of grove and lake, charmingly set off by the contrasting ocean. Between the patches of verdure there is a flat, water-covered table of coral rock, which is covered

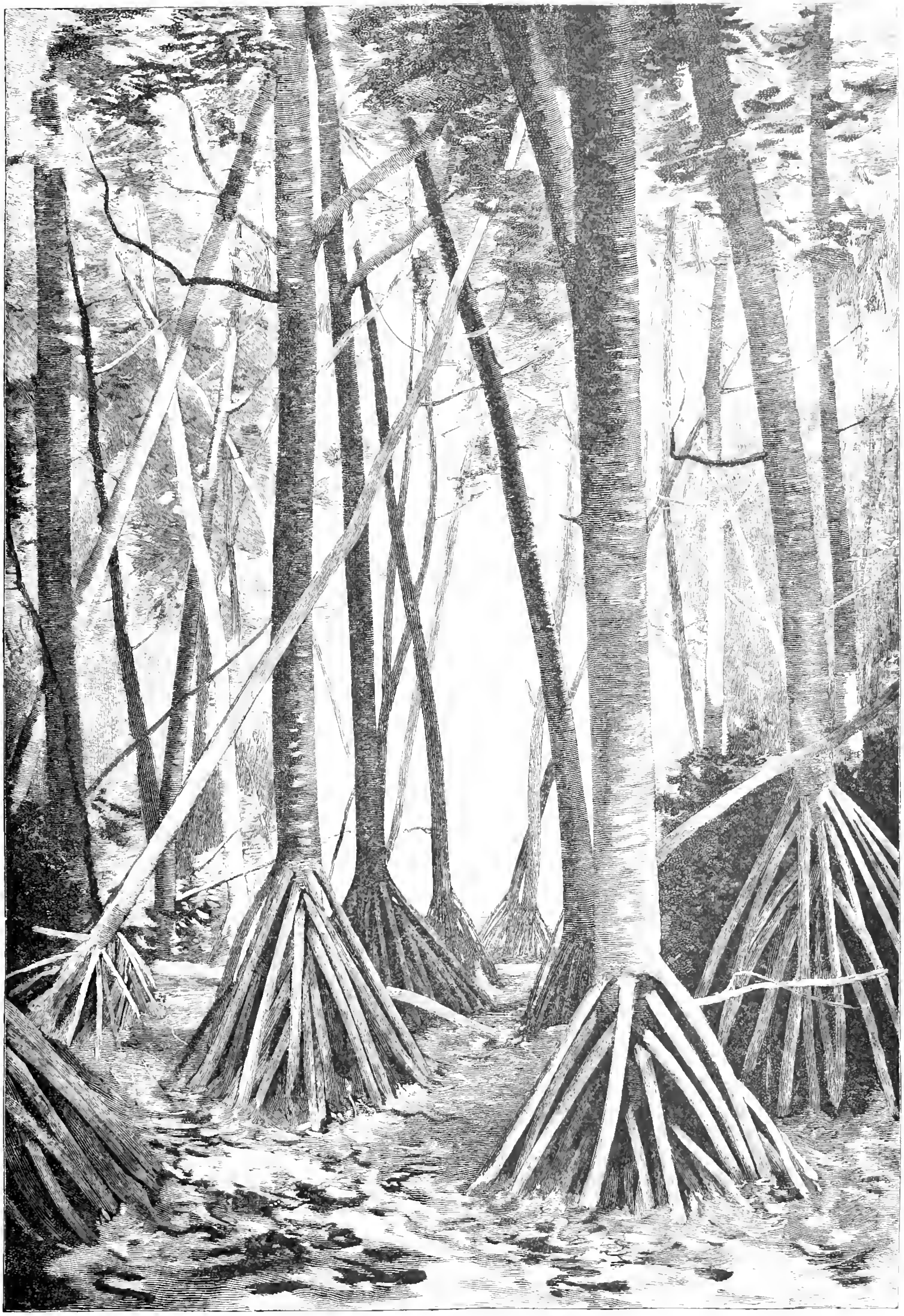


FIG. 6.—GROUP OF PANDANUS TREES.

Fig. 7.—Beach of Lagoon (looking north).

Fig. 8.—Beach of Lagoon (looking south).

with little coral heads which show at low water. On some of the islands there are spaces void of vegetation, extending from lagoon to sea-beach, which indicate the existence at a former time of a water separation.

"The inclosing platform reef fringes the shore, forming a wide extension, elevated at its outer edge, around the greater portion of which the surf breaks with considerable violence. There is a passage through, or over, this bordering reef near the southern end, which is deep enough to permit small ships' boats to penetrate to the lagoon at high water.

"The surface of the islands is covered with a growth of trees and other vegetation, much of which has been planted by the hand of man, especially large numbers of cocoa palms, which are being raised for the production of cocoanut-oil. The water in the lagoon is extremely salt, and evidently of greater density than the water of the outer sea.

"The climate of the island, though warm, is delightful, for, surrounded as it is by sea, the temperature is equable. The weather, though mostly fine, is somewhat changeable, with occasional sudden showers, which occur generally at night or during the early morning. The prevailing winds in April and May were from the N. and E.

"The following inscription exists, posted on a blackboard on the lower island:

"'Caroline Island, latitude 9° 56′ S., longitude 150° 06′ W. Leased from Her Most Gracious Majesty VICTORIA, Queen of Great Britain and Ireland, by Messrs. HOULDER, Bros. & Co., No. 146 Leadenhall st., London, England, and Fanning's Island, North Pacific Ocean. Agents: Mdme. T. SALMON, veuve BRANDER, Tahiti; THOMAS H. DAVIES, H. B. M. vice-consul, Honolulu; MACONDRAY & Co., San Francisco.'"

"There are some traces of former inhabitants, among which may be mentioned three houses and two sheds, in good repair, on the lower island, and two others on the northern island of the group. About one-third the distance up the lagoon a canvas hut exists on one of the smaller islets on the eastern side of the lagoon, and two wooden huts stand on one of the western islets, some distance further up the lagoon. At various places around the beach, anchors, chains, spars, and pieces of the woodwork of vessels may be seen, some of them, perhaps, being the remains of wrecks on the reef in years gone by. The island is inhabited at the present time by seven persons, four men, one woman, and two children, who are engaged in the planting and care of the young cocoanut trees now about 3 feet high.

"Some varieties of phosphatic guano are found on the islets, but at the present time there seems to be no effort to export any. The source of fresh water on Caroline, as on many coral islands, is the rains, which percolate through the sands and collect upon the coral rock, which forms the basis of the island. There are two shallow wells on the lower island, and another on the upper or northern island.

"Tidal observations made in the lagoon show no relation between the rise and fall in the lagoon and that outside. The lagoon is open to windward, and the wind evidently exercises great influence over the height of the water."

The brick piers which we constructed for the support of our instruments, and the frames of our observatories, which we left standing, will serve to signalize our occupation of the island.

In particular I placed upon the upper surface of the pier of the transit instrument a marble slab bearing the inscription, "U. S. Eclipse Party, 1883, May 6." This marks the point to which our latitude and longitude are referred.

It may be added that a series of tidal observations was made by Lieutenant QUALTROUGH and Messrs. FLETCHER and DOYLE. These show the lunar tidal interval on the day of full and chonge to be $4^h$; that is, the time of high water water is $4^h$ later than the moon's transit. The greatest daily range was 1′ 7″; the least daily range was 0′ 5″.

§ 3. LONGITUDE OF CAROLINE ISLAND.—BY MR. WINSLOW UPTON.

The longitude of Caroline Island was determined by means of chronometers and from observations of moon culminations. The care of the chronometers was in the hands of Ensign BROWN from the time of leaving New York until March 24, after leaving Callao in the *Hartford*, and in my hands for the rest of the voyage. The observations for time with the transit on Caroline Island were made by Mr. PRESTON, as well as the observation of moon culminations. The reduction of the work was assigned me; this report therefore incorporates the work done by these members of the party as far as it bears upon the determination of the longitude.

LONGITUDE FROM CHRONOMETERS.

The following chronometers were carried on the expedition: NEGUS, 1340, mean time; NEGUS, 1536, sidereal time; NEGUS, 1589, sidereal time; HUTTON, 202, sidereal time; BLISS, 2876, sidereal time.

The first two were brought from the United States Naval Observatory with their corrections determined at Washington. The third and fourth were brought from the office of the United States Coast and Geodetic Survey with their corrections undetermined. The fifth was brought by Professor HOLDEN, not running, and was started on the second day after leaving New York. The corrections at the beginning of the voyage of the last three chronometers were obtained by comparison with the first. On the *Hartford* regular comparisons were made with the chronometers of the ship as follows: BOND, 233, mean time; NEGUS, 1288, mean time; NEGUS, 1065, mean time; WOOD, 425, mean time. For the greater part of the expedition nine chronometers therefore were in use. On the *Zealandia*, from Honolulu to San Francisco, comparisons were made with the two chronometers of that ship, but were not used in the reductions.

Throughout the journey from New York to San Francisco daily comparisons were made of the several chronometers. At New York observations of the time-ball checked the running of 1340 and 1536 from Washington. At Aspinwall the local time was obtained by sextant observations, and by comparison with the chronometer of the Royal Mail steamer *Medway*, FLETCHER, 1608. At Callao no observations were made, the local time adopted depending upon comparisons with the *Hartford* and values deduced from the rates of the chronometers. At Caroline Island sextant observations were made until the mounting of the transit. At Honolulu sextant observations were made, and at San Francisco comparisons at the observatory of the United States Coast and Geodetic Survey with the chronometer of the transit of Venus party under the charge of Mr. EDWIN SMITH, the correction of which was determined by transit observations made by Prof. H. S. PRITCHETT. At Honolulu chronometers 202 and 1589 were left behind, and for the voyage from Honolulu to San Francisco but three chronometers in consequence were available. The following table contains the adopted chronometer corrections at the various places enumerated above. The chronometers are designated by their numbers, and the corrections are in Greenwich mean or sidereal time. Nos. 202 and 1589 were regulated to Washington time, but were set by Mr. PRESTON at Caroline Island to local sidereal time, which explains the change in the corrections. Nos. 1536 and 2786 were regulated to Caroline sidereal time. The others were running on Greenwich mean time.

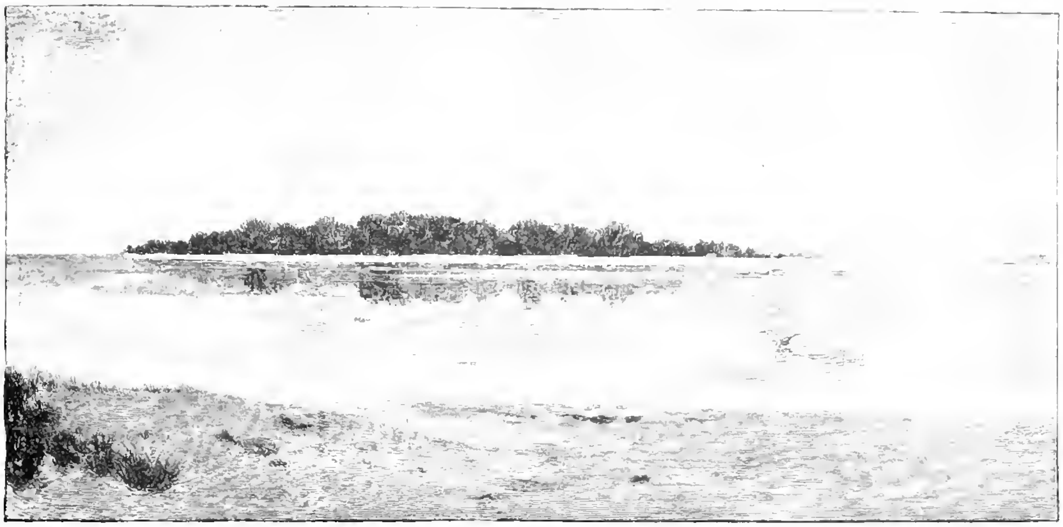


Fig. 9.—One of the small Islets bordering the Lagoon.

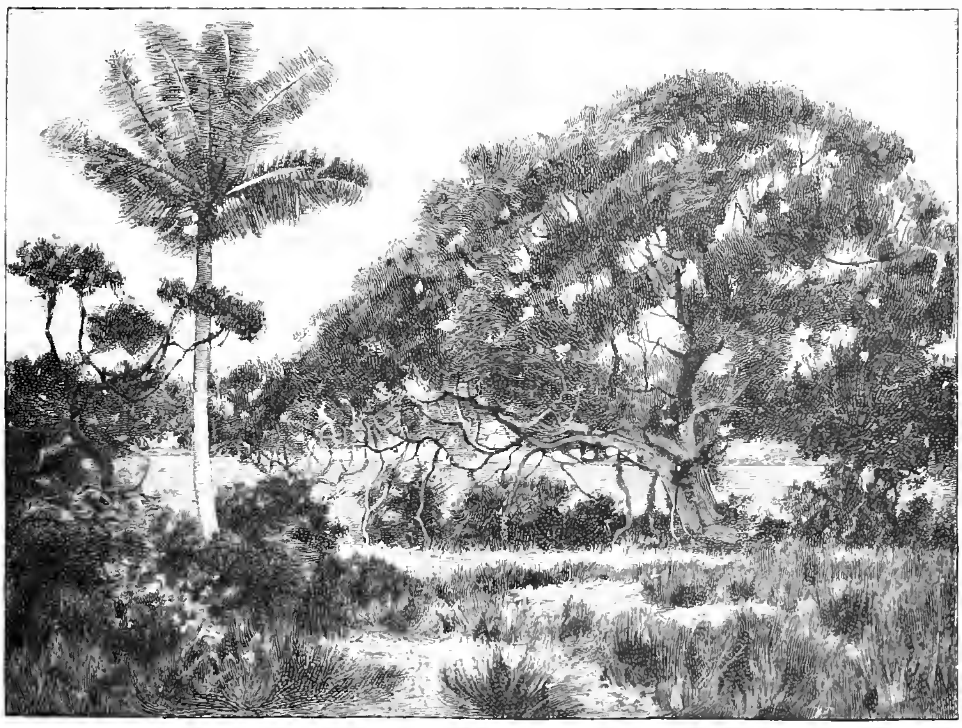


Fig. 10.—South Shore of the Lagoon.

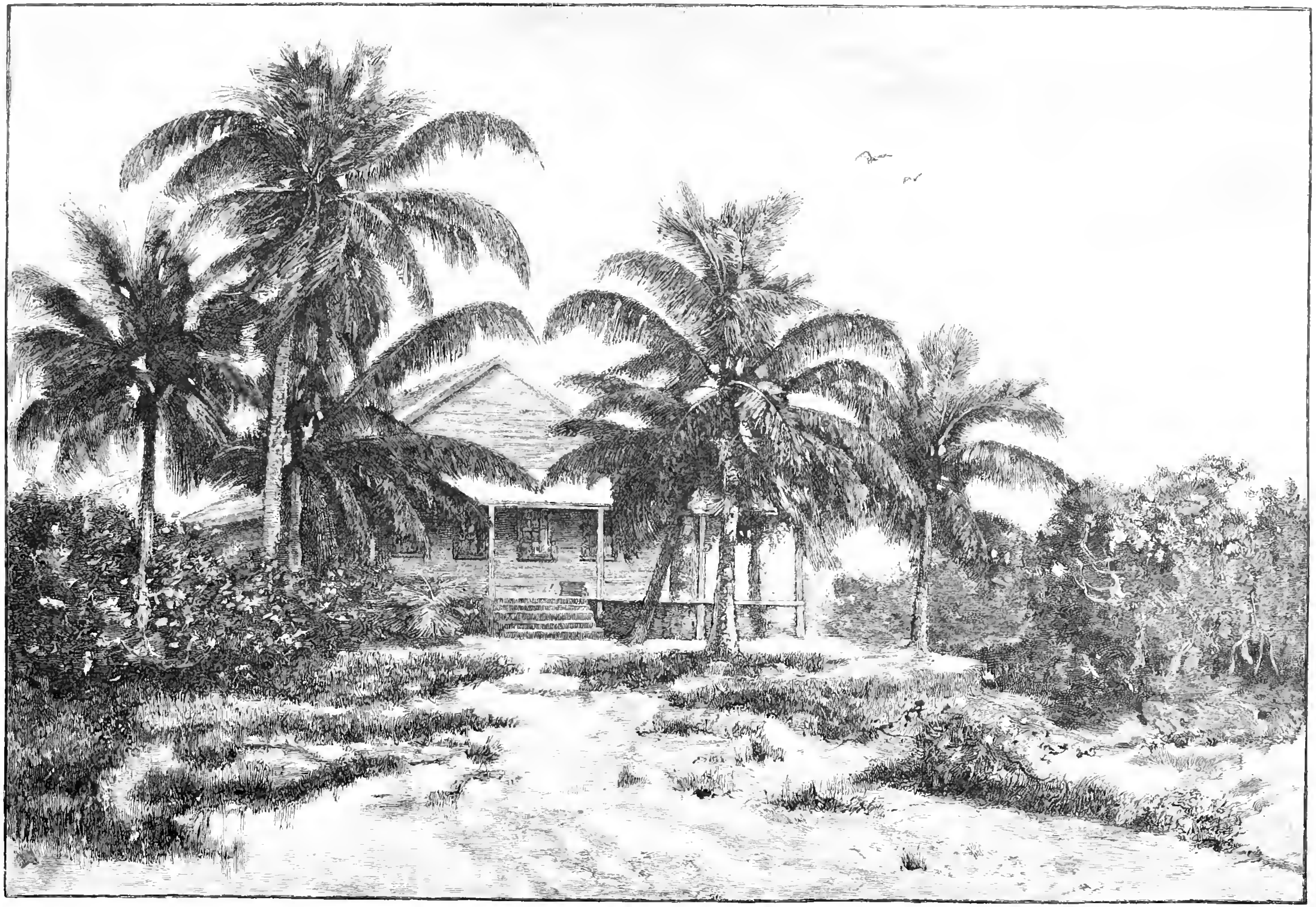


FIG. 11.—HOUSE ON CAROLINE ISLAND.

TABLE 1.—*Chronometer corrections in Greenwich mean or sidereal time.*

| Date. | Place. | 1340. | 202. | 1589. | 2786. |
|---|---|---|---|---|---|
| (*Washington time.*) | | *m. s.* | *h. m. s.* | *h. m. s.* | *h. m. s.* |
| Feb. 28.000 | Washington | —6 53.78 | - - - - - | - - - - - | - - - - - |
| Mar. 2.054 | At sea | - - - - - | + 5 7 29.7 | + 5 6 35.2 | - - - - - |
| Mar. 3.170 | At sea | - - - - - | - - - - - | - - - - - | +10 1 23.8 |
| Mar. 11.006 | Aspinwall | —7 3.8 | + 5 7 27.3 | + 5 7 10.3 | +10 0 57.3 |
| Mar. 22.140 | Callao | —7 10.3 | + 5 7 30.9 | + 5 7 49.7 | +10 0 21.5 |
| Mar. 23.968 | At sea | - - - - - | - - - - - | - - - - - | - - - - - |
| June 1.076 | Honolulu | —8 3.5 | +10 1 30.7 | +10 2 41.1 | + 9 55 51.0 |
| June 12.385 | San Francisco | —8 14.20 | - - - - - | - - - - - | + 9 55 3.73 |

| Date. | Place. | 1536. | 233. | 1288. | 1065. | 425. |
|---|---|---|---|---|---|---|
| (*Washington time.*) | | *h. m. s.* | *m. s.* | *m. s.* | *m. s.* | *m. s.* |
| Feb. 28.000 | Washington | +10 1 22.06 | - - - - | - - - - | - - - - | - - - - |
| Mar. 2.054 | At sea | - - - - - | - - - - | - - - - | - - - - | - - - - |
| Mar. 3.170 | At sea | - - - - - | - - - - | - - - - | - - - - | - - - - |
| Mar. 11.000 | Aspinwall | +10 1 39.3 | - - - - | - - - - | - - - - | - - - - |
| Mar. 22.140 | Callao | +10 1 55.1 | - - - - | - - - - | - - - - | - - - - |
| Mar. 23.968 | At sea | - - - - - | +17 24.0 | —5 31.1 | —4 26.4 | +1 57.3 |
| June 1.076 | Honolulu | +10 3 34.3 | +20 0.9 | —5 28.5 | —4 41.9 | +2 39.1 |
| June 12.385 | San Francisco | +10 3 47.78 | - - - - | - - - - | - - - - | - - - - |

With regard to the corrections given in the preceding table some explanations are necessary. The corrections on February 28.000 were determined at the United States Naval Observatory, those on March 2 and 3 by comparisons with 1340. The sextant observations at Aspinwall consist of three double altitudes of the sun, giving the correction to 1340 —$7^m$ $2^s.9$. The comparison with the chronometer of the *Medway* gave — $7^m$ $4^s.3$. Giving the latter double weight, as it was said to depend on equal altitude observations made the day previous, the correction —$7^m$ $3^s.8$ results. Corrections to the other chronometers were obtained by comparisons. They were used only in determining the chronometer rates from New York for obtaining the corrections at Callao.

The corrections to be adopted at Callao received especial attention, as it was intended to make this point one of the terminal points of the campaign. Unfortunately but two days were spent at this port, and no observations were made. The corrections therefore depend upon comparisons with the *Hartford* chronometers, and upon corrections deduced by using the rates from New York.

Comparisons with the chronometer 1288 of the *Hartford* were made on March 21, using 202 as a hack and 1340 as the standard for the expedition chronometers. These gave: 1340 — 1288 $=1^m$ $34^s.55$; 1288 corr. $-5^m$ $34^s.26$ (given by the navigator of the *Hartford*); 1340 corr. $-7^m$ $8^s.8$.

The correction to 1288 depends upon sextant observations made March 4, on shore, by the method of single altitudes brought forward by a rate determined for an interval of ninety-six days, and checked by a deck observation March 18. The correction was furnished through the kindness of the navigator of the *Hartford*. The computation of the chronometer corrections, by using the rates from New York, was thus made:

From the preceding table of corrections the mean rates were obtained New York to Aspinwall, and from the chronometer comparisons March 10, 11, 14, 15, the mean values of the relative rates between 1340 and each of the other chronometers. The temperatures changed greatly between New York and Aspinwall, but were more constant between Aspinwall and Callao. A rate determined at Aspinwall is therefore better for carrying forward the corrections from Aspinwall to Callao. The comparisons March 10, 11, were the last made on the *Acapulco*, and those March 14, 15, the first on the *Bolivia*; their mean was adopted for the relative rates at Aspinwall. The following table contains the mean rates of each chronometer New York to Aspinwall, the mean relative rates from these figures, then the relative rates at Aspinwall, obtained as above. The differences are large, and in the absence of any evidence as to the superiority of any one chronometer it is assumed that the differences should be distributed equally between 1340 and the chronometer compared with it in each case. The corrected rates of 1340 are therefore obtained as given in the sixth column, and the mean taken, rejecting the comparison with 202, as it was the hack chronometer and ran irregularly. The rates in the last column are the values adopted for the rates at Aspinwall.

TABLE II.—*Rates of each chronometer at Aspinwall.*

| Chronometer. | Mean rate, New York to Aspinwall. | Relative rate 1340 *minus* each. | Relative rate at Aspinwall. | Difference. | Rate of 1340 from each chronometer. | Adopted rate at Aspinwall. |
|---|---|---|---|---|---|---|
| | *s.* | *s.* | *s.* | *s.* | *s.* | *s.* |
| 1340 | + 0.91 | - - - - | - - - - | - - - - | - - - - | + 0.72 |
| 202 | + 0.27 | + 0.64 | + 0.92 | + 0.28 | [+ 1.05] | — 0.20 |
| 1589 | — 3.92 | + 4.83 | + 4.38 | — 0.45 | + 0.69 | — 3.66 |
| 2786 | + 3.38 | — 2.47 | — 2.78 | — 0.31 | + 0.75 | + 3.50 |
| 1536 | — 1.57 | + 2.48 | + 2.12 | — 0.36 | + 0.73 | — 1.40 |

The chronometer comparisons between Aspinwall and Callao showed departures from the above values. These comparisons were treated in a manner similar to that above given for determining a correction to the rate of 1340, and hence to that of each chronometer. The following table gives the results:

TABLE III.—*Mean rates adopted, Aspinwall to Callao.*

| Chronometer. | Adopted rate at Aspinwall. | Relative rate 1340 *minus* each. | Relative rate from chronometer comparisons. | Difference. | Rate of 1340 from each chronometer. | Adopted rate, Aspinwall to Callao. |
|---|---|---|---|---|---|---|
| | *s.* | *s.* | *s.* | *s.* | *s.* | *s.* |
| 1340 | + 0.72 | - - - - | - - - - | - - - - | - - - - | + 0.71 |
| 202 | — 0.20 | + 0.92 | + 1.12 | + 0.20 | [+ 0.82] | — 0.41 |
| 1589 | — 3.66 | + 4.38 | + 4.16 | — 0.22 | + 0.61 | — 3.45 |
| 2786 | + 3.50 | — 2.78 | — 2.61 | + 0.17 | + 0.81 | + 3.32 |
| 1536 | — 1.40 | + 2.12 | + 2.08 | — 0.04 | + 0.70 | — 1.37 |

By means of the rates given in the last column of Table III, the correction of each chronometer was obtained for the time of the first comparison of chronometers in Callao Harbor after their removal to the *Hartford*. The resulting corrections of 1340 from each chronometer (rejecting 202) are:

*Corr. to* 1340, *March* 22.140.

| | *m.* *s.* |
|---|---|
| By rate - - - - - - - - - - - - - - - - | —7 11.7 |
| From 1589 - - - - - - - - - - - - - - | 11.3 |
| 2786 - - - - - - - - - - - - - - | 11.5 |
| 1536 - - - - - - - - - - - - - - | 10.8 |
| Mean - - - - - - - - - - - - - - - - - | —7 11.3 |

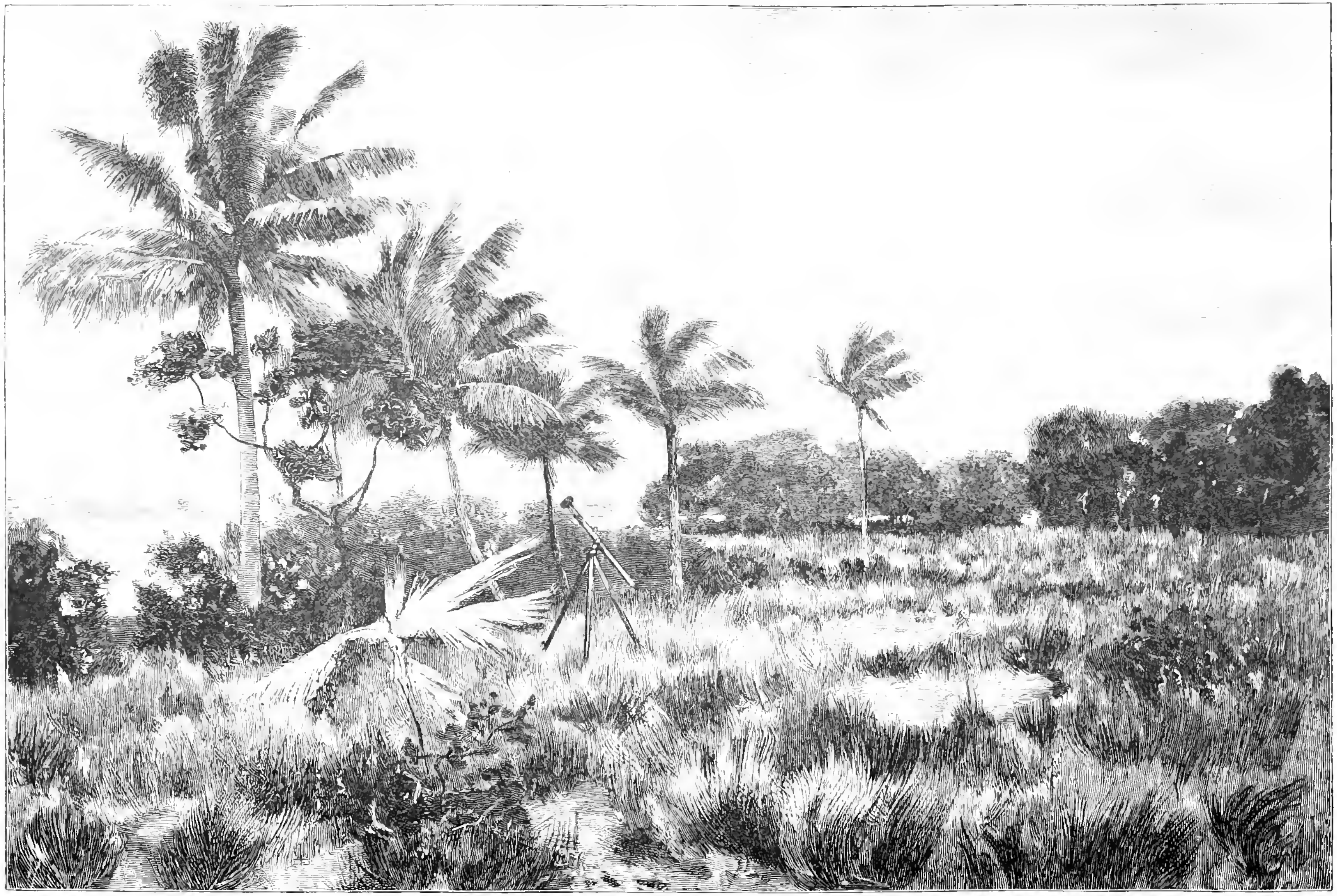


FIG. 12.—VIEW FROM CAMP HARTFORD TOWARDS THE LAGOON.

The correction given by comparison with the *Hartford* chronometer 1288 reduced to the above time by the rate of 1340 is $-7^m\ 9^s.3$. Adopting the mean $-7^m\ 10^s.3$, and deducing the corrections to the other chronometers, we have the corrections already given in Table I. Comparisons with all the chronometers of the *Hartford* were first made on March 24. Carrying forward the correction of 1340 by its assumed rate $+0^s.71$, we have the corrections given in Table I on that date.

It will be seen that the corrections adopted at Callao are uncertain by an amount which may reach several seconds. The uncertainties arise from the necessary assumptions made in bringing forward the chronometer corrections, the unreliability of the observation at Aspinwall, and the possible errors in the corrections given for the *Hartford* chronometer 1288 due to the length of time since observations had been made and to the uncertainty in the longitude of Callao given on chart No. 784, United States Hydrographic Office. In the absence of direct observations at Callao, the corrections adopted are the best attainable.

At Honolulu observations with the sextant were attempted both morning and evening for several days after the arrival of the *Hartford*. Clouds, however, prevented observations by equal altitudes, but good observations by single altitudes were obtained on three occasions, giving the following corrections to 1340:

| | *m.* *s.* |
|---|---|
| May 30.392 | −8 2.4 |
| June 1.037 | 3.0 |
| June 2.034 | 4.4 |
| Mean, May 31.821 | −8 3.3 |

Reducing to June 1.076, the time of the nearest chronometer comparisons, we have the corrections given in Table I.

At San Francisco advantage was taken of a time determination made at the observatory of the United States Coast and Geodetic Survey, on the evening after the arrival of the expedition, by Messrs. EDWIN SMITH and H. S. PRITCHETT, of the United States Transit of Venus Expedition, through whose courtesy a comparison was made between the chronometers. The resulting corrections are given in Table I.

Determinations of the local time at Caroline Island were made by Mr. PRESTON with the transit instrument. Previous to the mounting of the instrument, observations with the sextant were made every morning and evening, which were reduced by the method of equal altitudes. The corrections in local time to 1340 by these observations were as follows, not including the sextant determinations on April 23, a. m., which it was considered unnecessary to use:

| *h.* | *h.* *m.* *s.* |
|---|---|
| April 20, 12 | −10 8 33.1 |
| 21, 0 | 34.0 |
| 21, 12 | 34.4 |
| 22, 0 | 34.6 |

On April 24, $7^h$, the transit determination of time gave the correction $-10^h\ 8^m\ 35^s.67$. From these determinations the correction for April 20, $23^h$, the time of the last comparisons on the *Hartford* before the removal of the chronometers to the shore, was deduced by using the sea rate

$+0^s.835$ up to the removal, and $+0^s.47$ after removal, the former being obtained in the computation later explained, and the latter the shore rate on Caroline Island. The following are the results:

Sextant observations:

| | | |
|---|---|---|
| | *h.* | *h. m. s.* |
| April 20, | 23 - - - - - | — 10 8 33.48 |
| | | 33.98 |
| | | 34.15 |
| | | 34.12 |
| Mean - - - - - - - - - - - - - - | | — 10 8 33.93 |

Transit mounted 140 feet west of site of sextant observations:

| | |
|---|---|
| | *h. m. s.* |
| Reduction to transit instrument - - - | — - - .09 |
| Resulting corr. (from sextant observations) - - - - - - - - - - - | — 10 8 34.02 |
| Resulting corr. (from transit observations) - - - - - - - - - - - | — 10 8 34.06 |
| Mean - - - - - - - - - - - - - - - | — 10 8 34.04 |

Upon leaving Caroline Island, the last time determination with the transit instrument by Mr. Preston was carried forward by the rate $+0^s.47$ to the time of the first comparisons after the return of the chronometers to the *Hartford*. The computation was as follows:

| | | | |
|---|---|---|---|
| | *h. m.* | | *h. m. s.* |
| May 8, | 7 49, | local time corr. to 1340= | —10 8 42.33 |
| | | Red. - - - - - - | — .42 |
| | 9, 5 | local time - - - - - - | — 10 8 42.75 |

The following table gives the corrections on local mean or sidereal time for each of the nine chronometers before landing at Caroline Island and immediately upon leaving the island, derived from the chronometer comparisons and using the above corrections for 1340. The times are expressed in Washington mean time to correspond with those in Table I.

Table IV.—*Chronometer corrections at Caroline Island, expressed in local mean or sidereal time.*

| | April 21.161. | May 9.408. | Difference. |
|---|---|---|---|
| | *h. m. s.* | *h. m. s.* | *h. m. s.* |
| 1340 | — 10 8 34.04 | — 10 8 42.75 | — 0 0 8.71 |
| 202 | — 4 53 5.82 | + 14.75 | + 4 53 20.57 |
| 1589 | — 4 51 24.56 | + 40.85 | — 4 52 5.41 |
| 2786 | — 2 19.09 | — 3 35.35 | — 1 16.26 |
| 1536 | + 1 34.59 | + 2 4.95 | + 30.36 |
| 233 | — 9 42 35.41 | — 9 41 48.66 | + 46.75 |
| 1288 | — 10 6 33.10 | — 10 6 28.69 | + 4.41 |
| 1065 | — 10 5 33.45 | — 10 5 36.20 | — 2.75 |
| 425 | — 9 58 44.50 | — 9 58 28.27 | + 16.23 |

Chronometers 202 and 1589 were altered to local sidereal time for convenience in observations, and were frequently carried about on the island, the latter being used by Mr. Preston in connection with the chronograph. No. 1536 was moved occasionally, and 1340 only once, on the day of the eclipse, the latter being kept carefully as the standard of reference. The observations with the transit showed that on shore it had a gaining rate of 0ˢ.47, a much smaller value than its sea rate. No. 2786 was not removed from the vessel.

We are now ready to determine the longitude from the chronometers, making use of the Greenwich corrections given in Table I, and the Caroline Island corrections given in Table IV. Two chronometers, 1340 and 1536, are available for the journey, New York to San Francisco, and the whole nine between Callao and Honolulu. The following table contains the mean rates of each chronometer and the resulting longitude. In obtaining the former the differences between the chronometer corrections at New York, Callao, Honolulu, and San Francisco (Table I) were taken and diminished by the changes which took place during the stay at Caroline Island (Table IV, last column). Dividing these by the respective intervals of time, diminished by that from April 21 to May 9, we have the mean sea rates of the chronometers. This assumes that the rates of those chronometers, viz, 1340, 202, 1589, and 1536, which were removed to the island, and were observed to have different rates on shore, returned to their former traveling rates after the resumption of the voyage. The daily chronometer comparisons show the same relative rates after leaving Caroline Island as before arrival, and hence justify the assumption, except in the case of 1589, which had been used in the transit observations on shore and also had had its hands moved. A correction to the longitude was therefore obtained for this chronometer by summing up the departures of the observed relative rates between 1340 and 1589 from their mean values, the resulting longitude being given in the sixth column. By means of the rates given in columns two and three the Greenwich corrections were obtained for the times April 21.161, and May 9.408, and the local corrections from Table IV at those dates subtracted from them. Both of the computations give the same longitude, and are simply a numerical check on each other.

TABLE V.—*Chronometer rates and longitude.*

| Chronometer. | Mean daily rate. | | Longitude. | | |
|---|---|---|---|---|---|
| | I.—New York to San Francisco | II.—Callao to Honolulu. | I. | II. | II.—Adopted. |
| | *s.* | *s.* | *h. m. s.* | *h. m. s.* | *s.* |
| 1340 | + 0.833 | + 0.845 | 10 0 56.83 | 10 0 58.4 | 58.4 |
| 202 | - - - - - - | — 0.744 | - - - - - - | 59.0 | - - - - - - |
| 1589 | - - - - - - | — 3.207 | - - - - - - | 50.6 | 58.7 |
| 2786 | - - - - - - | + 3.686 | - - - - - - | 50.0 | - - - - - - |
| 1536 | — 1.339 | — 1.306 | 10 0 57.33 | 59.7 | 59.7 |
| 233 | - - - - - - | — 2.165 | - - - - - - | 60.4 | 60.4 |
| 1288 | - - - - - - | — 0.024 | - - - - - - | 59.7 | 59.7 |
| 1065 | - - - - - - | + 0.250 | - - - - - - | 60.0 | 60.0 |
| 425 | - - - - - - | — 0.503 | - - - - - - | 56.0 | 56.0 |
| Mean | - - - - - - | - - - - - - | 10 0 57.1 | 10 0 | 59.0 |

The last column contains the seconds of the longitude used in deriving the mean result. Nos. 202 and 2788 were both excluded, the former because of its daily use as a hack, and its poor running, shown by the daily comparisons; the latter also for its poor running. (See Table of rates.)

It remains to inquire if any corrections can be obtained to the resulting longitude from the daily comparisons. This is unnecessary in the case of 1340 and 1536 between New York and San Francisco, as but two chronometers were used, and the corrections, if obtained, would simply reduce each to the mean of the two. The comparisons between Callao and Honolulu show a fine agreement from day to day, probably due in part to the almost constant temperatures to which they were exposed. A correction to 1589 was obtained, as above explained, and applied in the last column, but for the other chronometers it was found that the corrections would change the result by only 0.2 second, a quantity within the errors of the computation. The adopted values of the longitude are therefore:

| h. m. s. | |
|---|---|
| 10 0 59.0, | Callao to Honolulu (7 chronometers). |
| 10 0 57.1, | New York to San Francisco (2 chronometers). |

During the stay upon Caroline Island the *Hartford* visited Tahiti, where time determinations were made by the navigator of the vessel, which have kindly been furnished, as follows:

| | | m. s. |
|---|---|---|
| April 30. | 233 slow | 18 40.22 |
| | 1288 fast | 5 37.75 |
| | 1065 fast | 4 41.76 |
| | 425 slow | 2 16.65 |

The observations were made by equal altitudes with the sextant and I assume for Muta Uta Island, lat., $-17^\circ 31' 39''$; long., $149^\circ 34' 21''$.

Reducing these values to April 21 and May 9, by rates determined from the comparisons at Caroline Island on those dates, and comparing with the local corrections (Table IV), we have the following values of the longitude:

| | h. m. s. |
|---|---|
| 233 | 10 0 52.47 |
| 1288 | 53.17 |
| 1065 | 53.05 |
| 425 | 53.11 |
| Mean | 10 0 53.0 |

The assumed position of Muta Uta Island is taken from the revised edition of BOWDITCH *Navigator*, but its authority and reliability could not be obtained.

### LONGITUDE FROM MOON CULMINATIONS.

Observations of moon culminations were obtained by Mr. PRESTON on April 25, and 27, and 28. The last, however, cannot be used, as clouds prevented the determination of the position of the instrument. Three moon-culminating stars were obtained on the first night, but clouds interfered with the observations on the second, necessitating the determination of the constants of the instrument by the other stars observed. The computed right ascensions of the moon are as follows:

| | h. m. s. |
|---|---|
| April 25 | 17 22 20.09, from $\omega$ Ophiuchi. |
| | 20.10, from $\xi$ Ophiuchi. |
| | 20.11, from 58 Ophiuchi. |
| | 17 22 20.10, mean. |
| April 27 | 19 12 41.34. |

The resulting longitudes were obtained with the aid of the lunar ephemeris of the American ephemeris and are given below. Through the courtesy of the Superintendent of the United States

Naval Observatory, the observation of moon culminations made at Washington have been reduced, and their results communicated, as follows:

| Date. | Moon's R. A. | Corr. to Eph. |
|---|---|---|
| | *h. m. s.* | *s.* |
| April 24 | 16 17 22.47 | — 0.12 |
| 26 | 18 6 6.14 | 0.00 |
| 27 | 19 1 25.49 | — 0.11 |
| 29 | 20 52 6.25 | — 0.21 |

The observation on April 27 can therefore be reduced by direct comparison with the observation at Washington, and that of April 25 by applying to the ephemeris place the correction — 0ˢ.11, which increases the longitude by 3ˢ.1. The following are the resulting longitudes:

| Date. | Eph. uncorrected. | Corrected. |
|---|---|---|
| | *h. m. s.* | *h. m. s.* |
| April 25 | 10 0 51.9 | 10 0 55.0 |
| 27 | 10 0 52.9 | 10 0 55.6 |
| Mean | - - - - - - - - - - | 10 0 55.3 |

RESULTING LONGITUDE.

From the preceding sections we have the following values of the longitude:

| *h. m. s.* | |
|---|---|
| 10 0 59.0. | Seven chronometers, Callao to Honolulu. |
| 10 0 57.1. | Two chronometers, New York to San Francisco. |
| 10 0 53.0. | Four chronometers from Tahiti. |
| 10 0 55.3. | Two moon culminations. |

On account of the uncertainty in the assumed position of Tahiti it was decided not to use the third value given above, but to take the mean of the other three, giving the first double weight. The resulting longitude is—

$$\left.\begin{array}{r} 10^h\ 0^m\ 57^s.6 \\ 150^\circ\ 14'\ 24'' \end{array}\right\}\text{ west from Greenwich.}$$

## ADDENDUM.

### TABLE OF CHRONOMETER RATES, AND OBSERVATIONS WITH THE SEXTANT FOR TIME AND LATITUDE.

*Relative Chronometer rates.*

The following table contains the relative daily rate of each chronometer referred to 1340, deduced from the chronometer comparisons, and designed to check the running of the chronometers. The rates between New York and Callao were also used, as previously explained, in determining the corrections at Callao. The discordancies in the first part of the voyage are doubtless due to the rapid change of temperature after leaving New York. Between Callao and Honolulu a maximum and minimum thermometer, placed near the chronometers, was daily read. The temperatures increased gradually from 72° to 86°, reaching the maximum off Caroline Island, and decreasing to 74° on the journey to Honolulu. The daily range was only 2° or 3°, and could not always be determined, because the motion of the vessel disturbed the indices of the thermometers. The rates in this part of the voyage were very constant, as will be seen from the table. Chronometer 202 was used as a hack. Chronometer 2786 ran poorly, and also its second hand was a little out of position, so that some confusion arose among the different observers as to which half-second to adopt in reading. The latter circumstance accounts for part of the discrepancies at Honolulu. The comparisons were in general made at 11 a. m., local time. The expedition chronometers were secured to the floor in the admiral's cabin; the ship's chronometers were in the navigator's room, with the exception of 425, which was in the admiral's cabin.

*Relative rates of chronometers from daily comparisons.*

[1340—Each chronometer. Rate given is for twenty-four hours preceding the corresponding date.]

NEW YORK TO ASPINWALL.

| Date. | | 202. | 1589. | 2786. | 1536. | Observer. |
|---|---|---|---|---|---|---|
| | | s. | s. | s. | s. | |
| March | 4 | + 0.69 | + 5.00 | — 0.60 | *+ 3.19 | S. J. Brown. |
| | 5 | + .28 | 4.68 | 2.49 | 2.23 | Do. |
| | 6 | — .13 | 4.66 | 1.84 | 2.56 | Do. |
| | 7 | + .47 | 5.06 | 2.14 | 2.52 | Do. |
| | 8 | .11 | 4.64 | 3.18 | 2.16 | Do. |
| | 9 | .35 | 4.68 | 3.41 | 2.32 | Do. |
| | 10 | .86 | 4.68 | 3.36 | 2.10 | Do. |
| | 11 | + .50 | + 4.35 | — 2.16 | + 2.13 | Do. |

*Probably an error of 1s in the comparison.

ASPINWALL TO CALLAO.

| Date. | | 202. | 1589. | 2786. | 1536. | Observer. |
|---|---|---|---|---|---|---|
| March | 14 | + 0.84 | + 4.21 | — 2.28 | + 2.13 | S. J. Brown. |
| | 15 | 1.49 | 4.27 | 3.31 | 2.13 | Do. |
| | 16 | 1.10 | 4.23 | 3.33 | 2.09 | Do. |
| | 17 | 1.22 | 4.22 | 3.20 | 1.87 | Do. |
| | 18 | 1.45 | 4.13 | 2.29 | 2.15 | Do. |
| | 19 | 1.18 | 4.12 | 2.00 | 2.09 | Do. |
| | 20 | 1.22 | 4.12 | 2.37 | 2.17 | Do. |
| | 21 | + 0.48 | + 3.98 | 2.12 | 1.98 | Do. |

NOTE.—Between New York and Aspinwall, the air temperatures changed from 48° to 77°; between Panama and Callao, from 77° to 63°.

CALLAO TO CAROLINE ISLAND.

| Date. | | 202. | 1589. | 2786. | 1536. | 233. | 1283. | 1065. | 425. | Observer. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | s. | s. | s. | s. | s. | s. | s. | s. | |
| March | 22 | + 0.73 | + 4.00 | — 2.47 | + 1.89 | - - - | - - - | - - - | - - - | S. J. Brown. |
| | 23 | — .57 | 4.07 | — 2.04 | 1.88 | - - - | - - - | - - - | - - - | Do. |
| | 24 | + .59 | 4.18 | 1.56 | 1.80 | - - - | - - - | - - - | - - - | Do. |
| | 25 | + 1.21 | 4.24 | 2.56 | 1.96 | + 2.76 | + 0.75 | + 0.43 | + 0.87 | W. Upton. |
| | 26 | 1.77 | 4.33 | 2.41 | 1.98 | 2.92 | .81 | .48 | 1.24 | Do. |
| | 27 | 1.90 | 4.37 | 1.91 | 1.97 | 2.93 | .87 | .49 | 1.10 | Do. |
| | 28 | 2.32 | 4.22 | 2.20 | 1.98 | 2.97 | .81 | .41 | 1.21 | Do. |
| | 29 | 2.32 | 4.20 | 2.24 | 2.03 | 2.88 | 1.04 | .38 | 1.29 | Do. |
| | 30 | 1.85 | 4.28 | 1.63 | 1.98 | 2.95 | 1.02 | .50 | 1.32 | Do. |
| | 31 | 1.94 | 4.43 | 2.06 | 2.09 | 2.97 | 1.09 | .68 | 1.27 | Do. |
| April | 1 | 2.07 | 4.47 | 1.81 | 2.17 | 2.92 | 0.83 | .57 | 1.32 | Do. |
| | 2 | 2.45 | 4.45 | 2.07 | 2.10 | 2.98 | .94 | .77 | 1.48 | Do. |
| | 3 | 2.20 | 4.42 | 2.38 | 2.10 | 2.92 | .72 | .61 | 1.35 | Do. |
| | 4 | 2.57 | 4.30 | 2.03 | 2.14 | 3.02 | .89 | .65 | 1.35 | Do. |
| | 5 | 2.08 | 4.30 | 2.62 | 2.23 | 2.97 | .77 | .57 | 1.27 | Do. |
| | 6 | 2.73 | 4.51 | 2.57 | 2.22 | 3.03 | .84 | .68 | 1.25 | Do. |
| | 7 | 2.82 | 4.44 | 2.52 | 2.30 | 2.92 | .83 | .57 | 1.10 | Do. |
| | 8 | 2.29 | 4.45 | 2.25 | 2.23 | 3.05 | .88 | .67 | 1.30 | Do. |
| | 9 | 2.45 | 4.46 | 2.60 | 2.27 | 3.07 | .90 | .69 | 1.58 | Do. |
| | 10 | 1.97 | 4.50 | 2.30 | 2.15 | 3.04 | .97 | .63 | 1.55 | Do. |
| | 11 | 1.09 | 4.37 | 2.86 | 2.17 | 2.94 | .68 | .53 | 1.55 | Do. |
| | 12 | 0.74 | 4.27 | 2.97 | 2.25 | 2.93 | .79 | .58 | 1.71 | Do. |
| | 13 | 1.06 | 4.20 | 3.00 | 2.13 | 2.89 | .74 | .53 | 1.55 | Do. |
| | 14 | 1.50 | 4.16 | 2.81 | 2.14 | 2.93 | .79 | .47 | 1.65 | Do. |
| | 15 | 1.28 | 8.20 | 3.18 | 2.17 | 3.00 | .76 | .57 | 1.70 | Do. |
| | 16 | 1.19 | 4.24 | 3.32 | 2.08 | 2.86 | .72 | .52 | 1.64 | Do. |
| | 17 | 1.04 | 4.32 | 3.31 | 2.11 | 2.90 | .74 | .47 | 1.66 | Do. |
| | 18 | 0.51 | 4.17 | 3.14 | 2.25 | 3.03 | .77 | .54 | 1.87 | Do. |
| | 19 | 0.12 | 4.16 | 3.41 | 2.18 | 2.95 | 0.87 | 0.51 | 1.83 | Do. |
| | 20 | 0.87 | 4.19 | 3.28 | 2.15 | 2.99 | 0.79 | 0.52 | 1.63 | Do. |
| | 21 | + 0.39 | *+ 4.75 | — 3.40 | + 2.24 | + 2.76 | + 0.66 | †+ 0.16 | + 1.71 | Do. |

* Chronometer carried to and from shore. † Checked by a second comparison.

NOTE.—The comparisons on March 22 were made in Callao Harbor; those on April 20 and 21 while the *Hartford* was lying off Caroline Island.

CAROLINE ISLAND TO HONOLULU.

| Date. | | 202. | 1589. | 2786. | 1536. | 233. | 1288. | 1065. | 425. | Observer. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | s. | s. | s. | s. | s. | s. | s. | s. | |
| May | 10 | + 2.17 | + 3.91 | − 3.31 | + 2.20 | + 3.16 | + 0.86 | + 0.51 | + 1.49 | W. UPTON. |
| | 11 | 2.41 | 3.87 | 3.64 | 2.29 | 3.10 | .80 | .50 | 1.49 | Do. |
| | 12 | 2.25 | 3.81 | 3.61 | 2.33 | 3.26 | .85 | .58 | 1.49 | Do. |
| | 13 | 1.70 | 3.84 | 3.28 | 2.26 | 3.07 | .79 | .43 | 1.43 | Do. |
| | 14 | 1.85 | 4.06 | 3.41 | 2.29 | 3.16 | .74 | .49 | 1.45 | Do. |
| | 15 | 1.95 | 3.62 | 3.70 | 2.24 | 3.09 | .81 | .52 | 1.49 | Do. |
| | 16 | 1.76 | 3.70 | 3.64 | 2.23 | 3.12 | .88 | .55 | 1.41 | Do. |
| | 17 | 1.68 | 3.70 | 3.79 | 2.21 | 3.02 | .79 | .48 | 1.35 | Do. |
| | 18 | 1.71 | 3.60 | 3.79 | 2.22 | 3.14 | .90 | .59 | 1.38 | Do. |
| | 19 | 1.69 | 3.69 | 3.87 | 2.18 | 3.14 | .87 | .51 | 1.39 | Do. |
| | 20 | 1.65 | 3.61 | 3.78 | 2.04 | 2.89 | .90 | .51 | 1.27 | Do. |
| | 21 | 1.55 | 3.55 | 3.40 | 2.02 | 2.33 | .83 | .46 | 1.05 | Do. |
| | 22 | 1.50 | 3.58 | 3.24 | 1.95 | 3.17 | .73 | .40 | 0.99 | Do. |
| | 23 | 1.53 | 3.55 | 2.88 | 2.03 | 2.86 | .89 | .61 | 1.02 | Do. |
| | 24 | 1.47 | 3.65 | 2.66 | 2.12 | 3.03 | 1.04 | .86 | 1.09 | Do. |
| | 25 | 1.64 | 3.74 | 2.49 | 2.27 | 3.23 | 1.09 | .90 | 1.13 | Do. |
| | 27 | 1.05 | 3.81 | 2.29 | 2.28 | 3.26 | 1.13 | 0.95 | 1.27 | S. J. Brown. |
| | 28 | 1.23 | 3.36 | 3.28 | 2.32 | 3.22 | 1.18 | 1.04 | 1.08 | Do. |
| | 29 | 1.27 | 3.68 | 2.55 | 2.32 | 3.16 | 1.04 | 0.99 | 1.02 | W. UPTON. |
| | 30 | 1.50 | 3.56 | 2.20 | 2.23 | 3.06 | 1.04 | 0.82 | 0.89 | Do. |
| | 31 | 1.09 | 3.70 | 4.04 | 2.23 | - - - | - - - | - - - | 0.98 | E. S. HOLDEN. |
| June | 1 | 1.54 | 3.61 | 3.00 | 2.28 | 3.28 | 0.94 | 0.80 | 1.18 | W. UPTON. |
| | 2 | 1.81 | 3.80 | 2.96 | 2.25 | 3.25 | 1.11 | 0.66 | 1.42 | E. S. HOLDEN. |
| | *3 | 1.20 | 3.70 | 2.87 | 2.12 | - - - | - - - | - - - | 1.02 | |
| | †3 | + 0.68 | + 3.26 | − 2.89 | + 1.75 | + 2.83 | + 0.48 | + 0.39 | + 0.63 | W. UPTON. |

*A. M. †P. M.

NOTE.—On May 24 the *Hartford* anchored in Hilo Harbor, remaining until the 29th, and arriving at Honolulu on the 30th. The comparisons on June 3, which were made before the chronometers were moved from the *Hartford*, indicate quite plainly that 1340 lost half a second between the morning and afternoon comparison. The winding was done before the former comparison, and there is nothing to explain the discrepancy.

HONOLULU TO SAN FRANCISCO.

| Date. | | 2786. | 1536. | Observer. |
|---|---|---|---|---|
| June | 4 | *− 3.67 | *+ 1.62 | W. UPTON. |
| | 5 | 3.04 | 2.28 | Do. |
| | 6 | 3.12 | 2.30 | Do. |
| | 7 | 3.16 | 2.38 | Do. |
| | 8 | 3.47 | 2.36 | Do. |
| | 9 | 3.19 | 2.31 | Do. |
| | 10 | 3.06 | 2.31 | Do. |
| | 11 | 3.18 | 2.23 | Do. |
| A. M. | 12 | 3.05 | 2.03 | Do. |
| P. M. | 12 | 2.99 | 2.02 | Do. |
| | 13 | 2.98 | †1.77 | Do. |
| | 14 | − 3.12 | + 2.00 | Do. |

* These are derived from June 2, and confirm the change of $0^s.5$ in 1340 previously noted.

† Chronometer carried to and from observatory of United States Coast and Geodetic Survey in San Francisco.

NOTE.—The chronometers were secured in the pilot-house on the *Zealandia*. No. 2786 was used as a hack, and was carried daily into the captain's cabin to compare with the ship's chronometers. As these were not used in the reductions they have been omitted from the table. The *Zealandia* arrived in San Francisco in the evening of June 11. The temperatures in the pilot-house decreased between Honolulu and San Francisco from 80° to 60°.

## OBSERVATIONS FOR TIME.

[Aspinwall, March 11, 9.45 a. m. Double altitudes of sun. S. J. BROWN, observer. Chronometer, HUTTON, 202. E. D. PRESTON, recorder.]

| Time. | 2 alt.☉ | Remarks. | Index corrections. Off arc. | Index corrections. On arc. | Chronometer comparison. 1340. | Chronometer comparison. 202. |
|---|---|---|---|---|---|---|
| h. m. s. | ° ′ ″ | | ′ ″ | ′ ″ | h. m. s. | h. m. s. |
| 9 5 33.5 | 100 7 20 | Mercury tremulous on account of wind and surf. | 38 10 | 26 20 | 2 10 17.0 = | 8 11 19.5 |
| 11 11.0 | 101 40 40 | | 0 | 20 | 2 13 22.0 = | 8 14 25.0 |
| 14 39.0 | 103 18 10 | Good sight. | 10 | 40 | 4 12 28.0 = | 10 13 50.5 |
| | | | Correction, +5′ 50″ | | 4 15 30.0 = | 10 16 53.0 |

1340 fast, 7m 28.9. S. J. BROWN, computer.

[Caroline Island, April 20, p. m. Double altitudes of sun. W. UPTON, observer. Chronometer, NEGUS, 1589. C. S. HASTINGS, recorder.]

### INDEX CORRECTION.

| Before observation. Off arc. | Before observation. On arc. | After observation. Off arc. | After observation. On arc. |
|---|---|---|---|
| ° ′ ″ | ′ ″ | ° ′ ″ | ′ ″ |
| 359 21 40 | 25 40 | 359 22 0 | 25 40 |
| 50 | 40 | 0 | 50 |
| 50 | 30 | 10 | 40 |
| 30 | 40 | 20 | 40 |
| Corr. + 6′ 20″. | | Corr. + 6′ 5″. | |

Mean + 6′ 12″.

### I.

| Time. | 2 alt. ☉ | Time. | 2 alt. ☉ |
|---|---|---|---|
| h. m. s. | ° ′ | h. m. s. | ° ′ |
| 10 16 1.5 | 67 10 | 10 21 19.0 | 63 40 |
| 16 48.5 | 66 50 | 21 42.0 | 63 30 |
| 17 50.5 | 66 20 | 22 5.5 | 63 20 |
| 18 34.0 | 66 0 | 22 27.5 | 63 10 |

Above readings were through clouds.

W. UPTON, observer. W. B. FLETCHER, recorder.

### II.

| Time. | 2 alt. ☉ | Time. | 2 alt. ☉ |
|---|---|---|---|
| h. m. s. | ° ′ | h. m. s. | ° ′ |
| 10 32 22 | 59 40 | 10 34 46 | 57 30 |
| 32 42.5 | 59 30 | 35 6.5 | 57 20 |
| 33 4.5 | 59 20 | 35 29 | 57 10 |
| 33 26.5 | 59 10 | 35 50.5 | 57 0 |

Sky clear; conditions favorable.

CHRONOMETER COMPARISONS.

| 1340. | | 1589. |
|---|---|---|
| h. m. s. | | h. m. s. |
| 11 56 8.5 | = | 8 33 55 |
| 2 37 52.5 | = | 11 16 5 |

REDUCTION BY METHOD OF SINGLE ALTITUDES.

[W. Upton, computer.]

| | h. m. s. |
|---|---|
| 1589 fast— | 4 51 27.93 |
| 1340 fast— | 10 8 33.52 |

[Caroline Island, April 21, a. m. Double altitudes of sun. Chronometer, Negus, 1589. W. Upton, observer and recorder.]

INDEX CORRECTIONS.

| Before observation. | | After observation. | | Time. | 2 alt. ☉ | Time. | 2 alt. ☉ |
|---|---|---|---|---|---|---|---|
| Off arc. | On arc. | Off arc. | On arc. | | | | |
| ° ′ ″ | ′ ″ | ° ′ ″ | ′ ″ | h. m. s. | ° ′ | h. m. s. | ° ′ |
| 359 21 50 | 26 0 | 359 22 0 | 26 30 | 2 56 37.5 | 57 30 | 3 5 24.0 | 60 30 |
| 50 | 25 40 | 0 | 0 | 57 21.5 | 57 50 | 6 10 | 60 50 |
| 60 | 26 20 | Corr. + 5′ 52″.5 | | 58 4 | 58 10 | 6 53.5 | 61 10 |
| 50 | 26 10 | | | 58 48.5 | 58 30 | 7 37 | 61 30 |

Corr. + 6′ 2″.5 (2 wt). Adopted + 5′ 59″.2.

CHRONOMETER COMPARISONS.

| 1340. | | 1589. |
|---|---|---|
| h. m. s. | | h. m. s. |
| 5 16 36 | = | 1 57 10 |
| 8 4 29 | = | 4 45 30 |

REDUCTION BY METHOD OF SINGLE ALTITUDES.

| | h. m. s. |
|---|---|
| 1589 fast | 4 51 23.70 |
| 1340 fast | 10 8 32.60 |

Combining with observation April 20, p. m., made at nearly corresponding time. April 20, $12^h$, 1340, fast $10^h$ $8^m$ $33.1^s$.

Also combined with observation April 21, p. m., by method of equal altitudes. W. Upton, computer.

[Caroline Island, April 21, p. m. Double altitudes of sun. Chronometer, Negus, 1589. W. Upton, observer and recorder.]

INDEX CORRECTION.

| Before observation. | | After observation. | | Time. | 2 alt. ☉ | Time. | 2 alt. ☉ |
|---|---|---|---|---|---|---|---|
| Off arc. | On arc. | Off arc. | On arc. | | | | |
| ° ′ ″ | ′ ″ | ° ′ ″ | ′ ″ | h. m. s. | ° ′ | h. m. s. | ° ′ |
| 359 22 0 | 26 0 | 359 21 50 | 25 40 | 10 31 35.5 | 61 30 | 10 35 47.5 | 58 30 |
| 0 | 10 | 22 10 | 50 | 32 17.5 | 61 10 | 36 30.5 | 58 10 |
| 10 | 10 | 21 50 | 50 | 33 2.0 | 60 50 | 37 14.5 | 57 50 |
| 10 | 0 | 22 0 | 40 | 33 44.5 | 60 30 | 37 57.5 | 57 30 |
| Corr. + 5′ 55″ | | Corr. + 6′ 9″ | | | | | |
| Mean + 6′ 2″ | | | | | | | |

CHRONOMETER COMPARISONS.

| 1340. | |
|---|---|
| h. m. s. | h. m. s. |
| 1 20 56 | = 10 4 30 chron. 202. |
| 23 22.5 | = 10 5 15 chron. 1589. |
| 24 36 | = 5 13 30 chron. 1536. |

CHRONOMETERS REMOVED FROM SHIP TO THE SHORE.

| h. m. s. | h. m. s. |
|---|---|
| 2 9 53 | = 10 53 35 chron. 202. |
| 10 5 | = 52 5 chron. 1589. |
| 10 38.5 | = 5 59 40 chron. 1536. |

Reduction by method of equal altitudes, combining with observations April 21, a. m., and April 22, a. m. W. UPTON, computer.

[Caroline Island, April 22, a. m. Double altitudes of sun. Chronometer, NEGUS, 1589. W. UPTON, observer and recorder.]

I.

| Time. | 2 alt.☉ | Time. | 2 alt.☉ |
|---|---|---|---|
| h. m. s. | ° ′ | h. m. s. | ° ′ |
| 2 40 16.5 | 48 0 | 2 45 47 | 49 30 |
| 41 1.0 | 48 20 | 46 30 | 49 50 |
| 42 25.5 | 49 0 | 47 13 | 50 10 |
| 43 7.5 | 49 20 | 47 56.5 | 50 30 |

II.

| Time. | 2 alt.☉ | Time. | 2 alt.☉ |
|---|---|---|---|
| 3 0 46.5 | 57 30 | 3 9 37 | 60 30 |
| 1 30.5 | 57 50 | 10 21 | 60 50 |
| 2 13.5 | 58 10 | 11 4.5 | 61 10 |
| 2 56.5 | 58 30 | 11 47.5 | 61 30 |

INDEX CORRECTION.

| Before observation. | | After observation. | |
|---|---|---|---|
| Off arc. | On arc. | Off arc. | On arc. |
| ° ′ ″ | ′ ″ | ° ′ ″ | ′ ″ |
| 359 22 10 | 25 50 | 359 22 10 | 25 50 |
| 21 50 | 40 | 22 10 | 40 |
| 22 0 | 50 | 21 50 | 40 |
| 22 0 | 40 | 21 50 | 40 |
| Corr. + 6′ 9″ | | Corr. + 6′ 7″ | |

Mean + 6′ 8″

CHRONOMETER COMPARISONS.

| 1340. | 1589. |
|---|---|
| h. m. s. | h. m. s. |
| 5 31 41.5 | = 2 16 10 |
| 6 40 0.5 | = 3 24 40 |

Reduction by method of equal altitudes, combining with observations April 21, p. m., and April 22, p. m. W. UPTON, computer.

[Caroline Island, April 22, p. m. Double altitudes of the sun. Chronometer, NEGUS, 1589. W. UPTON, observer and recorder.]

I.

| Time. | 2 alt.☉ | Time. | 2 alt.☉ |
|---|---|---|---|
| h. m. s. | ° ′ | h. m. s. | ° ′ |
| 10 34 45.5 | 61 30 | 10 38 58.5 | 58 30 |
| 35 28 | 61 10 | 39 42 | 58 10 |
| 36 12.5 | 60 50 | 40 25.5 | 57 50 |
| 36 55.5 | 60 30 | 41 9 | 57 30 |

II.

| Time. | 2 alt.☉ | Time. | 2 alt.☉ |
|---|---|---|---|
| 10 56 17.5 | 50 30 | 11 1 4.5 | 49 20 |
| 57 0 | 50 10 | 1 47.5 | 49 0 |
| 57 43 | 49 50 | 3 12.5 | 48 20 |
| 58 26.5 | 49 30 | 3 56.0 | 48 0 |

INDEX CORRECTION.

| Before observation. | | After observation. | |
|---|---|---|---|
| Off arc. | On arc. | Off arc. | On arc. |
| ° ′ ″ | ° ′ | ° ′ ″ | ′ ″ |
| 359 22 5 | 26 0 | 359 21 40 | 26 0 |
| 0 | 0 | 21 40 | 25 40 |
| 0 | 5 | 21 50 | 25 40 |
| | | 21 50 | 26 0 |
| Corr. + 5′ 59″ | | Corr. + 6′ 12″ | |

Mean + 6′ 6″

CHRONOMETER COMPARISONS.

| 1340. | 1589. |
|---|---|
| h. m. s. | h. m. s. |
| 1 29 49.5 | = 10 15 35 |
| 2 28 40 | = 11 14 35 |

Reduction by method of equal altitudes, combining with observations April 22, a. m. W. UPTON, computer. (Observations were also made April 23, a. m., but were not used in the reductions.)

## OBSERVATIONS FOR LATITUDE.

[Caroline Island, April 23. Double altitudes of the sun. Pocket watch No. 3649. W. UPTON, observer and recorder.]

| Time. | 2 alt. ☉ | Resulting latitude. |
|---|---|---|
| h. m. s. | ° ′ ″ | ° ′ ″ |
| 0 18 43 | 133 58 20 | — 9 59 30 |
| 20 30 | 133 45 10 | 54 |
| 21 30 | 133 38 0 | 48 |
| 23 43 | 133 20 0 | 57 |
| | 2 alt. ☉ | |
| | ° ′ ″ | |
| 25 10 | 132 4 50 | 45 |
| 26 15 | 131 55 0 | 57 |
| 27 2 | 131 48 20 | 45 |
| 28 45 | 131 32 30 | |
| | | Mean — 9 59 48 |

INDEX CORRECTION.

| Off arc. | On arc. |
|---|---|
| ° ′ ″ | ′ ″ |
| 359 22 0 | 25 50 |

Corr. + 6′ 5″

WATCH COMPARISON

| 1340. | 3649. |
|---|---|
| h. m. s. | h. m. s. |
| 10 48 30 = | 0 39 24 |

Reduction by method of circummeridian altitudes. W. UPTON, computer.

[Caroline Island, April 24. Double altitudes of the sun. Pocket watch No. 3649. W. UPTON, observer and recorder.]

| Time. | 2 alt. ☉ | Resulting latitude. |
|---|---|---|
| h. m. s. | ° ′ ″ | ° ′ ″ |
| 11 49 43 | 134 17 20 | — 9 59 37 |
| 50 57 | 20 30 | 41 |
| 52 8 | 23 10 | 42 |
| 53 15 | 25 40 | 31 |
| | 2 alt. ☉ | |
| 57 43 | 133 26 30 | 31 |
| 58 45 | 26 20 | 40 |
| 59 40 | 26 10 | 40 |
| 12 0 40 | 25 40 | 40 |
| | 2 alt. ☉ | |
| 3 22 | 134 26 0 | 55 |
| 4 25 | 24 20 | 51 |
| 5 18 | 22 40 | 48 |
| 6 23 | 20 10 | 48 |
| | | Mean — 9 59 42 |

INDEX CORRECTION.

| Before observation. | | After observation. | |
|---|---|---|---|
| Off arc. | On arc. | Off arc. | On arc. |
| ° ′ ″ | ′ ″ | ° ′ ″ | ′ ″ |
| 359 22 30 | 25 50 | 329 22 30 | 26 0 |
| 30 | 26 0 | Corr. + 5′ 45″ | |
| 30 | 0 | | |
| 30 | 0 | | |
| Corr. + 5′ 46″ adopted. | | | |

WATCH COMPARISONS.

| 1340. | 3649. |
|---|---|
| h. m. s. | h. m. s. |
| 9 45 0 = | 11 37 1 |
| 10 22 10 = | 0 14 13 |

Reduction by method of circummeridian altitudes. W. UPTON, computer.

## APPROXIMATE LATITUDE BY SEXTANT OBSERVATIONS.

| | ° ′ ″ |
|---|---|
| April 23 | — 9 59 48 |
| 24 | 42 |
| Mean | — 9 59 45 |

## OBSERVATIONS FOR TIME.

[Honolulu, May 30, p. m. Double altitudes of the sun. W. Upton, observer. Chronometer, Hutton, 202. S. J. Brown, recorder.]

I.

| Time. | 2 alt. ⊙ | Time. | 2 alt. ⊙ |
|---|---|---|---|
| h. m. s. | ° ' | h. m. s. | ° ' |
| 8 47 14.25 | 74 30 | 8 49 31 | 74 30 |
| 35 | 20 | 54 | 20 |
| 58.75 | 10 | 50 15.75 | 10 |
| 48 19.75 | 74 0 | 38.5 | 0 |

II.

| | | | |
|---|---|---|---|
| 9 5 58 | 66 0 | 9 8 17.75 | 66 0 |
| 6 19.75 | 65 50 | 40 | 65 50 |
| 42.5 | 40 | 9 2.5 | 40 |
| 7 4 | 65 30 | 23 | 65 30 |

INDEX CORRECTION.

| Before observation. | | After observation. | |
|---|---|---|---|
| Off arc. | On arc. | Off arc. | On arc. |
| ° ' '' | ' '' | ° ' '' | ' '' |
| 359 22 0 | 25 30 | 359 22 0 | 25 10 |
| 10 | 30 | 10 | 0 |
| 5 | 20 | - - - - | 15 |
| Corr. + 6' 14''. | | Corr. + 6' 23''. | |

Mean + 6' 19''.

CHRONOMETER COMPARISONS.

| 1340. | 202. |
|---|---|
| h. m. s. | h. m. s. |
| 1 45 30 = | 8 8 50 |
| 3 35 40 = | 9 59 18 |

## REDUCTION BY METHOD OF SINGLE ALTITUDES.

[W. Upton, computer.]

| | h. m. s. | |
|---|---|---|
| 202 slow | 10 1 29.5 | Greenwich sidereal time. |
| 1340 fast | 8 2.4 | Greenwich mean time. |

[Honolulu, June 1, a. m. Double altitudes of the sun. W. Upton, observer. Chronometer, Hutton, 202. Mrs. W. Upton, recorder.]

I.

| Time. | 2 alt. ⊙ | Time. | 2 alt. ⊙ |
|---|---|---|---|
| h. m. s. | ° ' | h. m. s. | ° ' |
| 0 48 8.5 | 61 10 | 0 50 29 | 61 10 |
| 31.5 | 20 | 52 | 20 |
| 52 | 30 | 51 12.5 | 30 |
| 49 15.5 | 61 40 | 35 | 61 40 |

II.

| | | | |
|---|---|---|---|
| 0 55 55 | 64 40 | 1 3 1.5 | 66 50 |
| 56 16.5 | 50 | 23.5 | 67 0 |
| 39.5 | 65 0 | 45.5 | 10 |
| 57 2 | 65 10 | 4 7.5 | 67 20 |

INDEX CORRECTION.

| Off arc. | On arc. |
|---|---|
| ° ' '' | ' '' |
| 359 22 10 | 25 30 |
| 5 | 30 |
| 0 | 30 |
| 0 | 20 |

Corr. + 6' 14''.

CHRONOMETER COMPARISONS.

| 1340. | 202. |
|---|---|
| h. m. s. | h. m. s. |
| 5 14 15 = | 23 44 2 |
| 7 5 10 = | 1 35 15 |

Somewhat disturbed by clouds and jarring of the mercury from passing carriages.

REDUCTION BY METHOD OF SINGLE ALTITUDES.

[W. UPTON, computer.]

| | h. m. s. | |
|---|---|---|
| 202 slow | 10 1 31.1 | Greenwich sidereal time. |
| 1340 fast | 8 3.0 | Greenwich mean time. |

[Honolulu, June 2, a. m. Double altitudes of the sun. W. UPTON, observer. Chronometer, HUTTON, 202. Mrs. W. UPTON, recorder.]

| Time. | 2 alt. ☉ | Time. | 2 alt. ☉ |
|---|---|---|---|
| h. m. s. | ° ′ | h. m. s. | ° ′ |
| 1 1 22.5 | 65 20 | 1 3 40.5 | 65 20 |
| 43.5 | 30 | 4 3.5 | 30 |
| 2 5.5 | 40 | 26.5 | 40 |
| 29 | 50 | 4 47.5 | 50 |

INDEX CORRECTION.

| Off arc. | On arc. |
|---|---|
| ° ′ ″ | ′ ″ |
| 359 22 0 | 25 20 |
| 21 50 | 15 |
| 22 0 | 10 |
| 22 0 | 0 |

Corr. + 6′ 26″

CHRONOMETER COMPARISONS.

| 1340. | | 202. |
|---|---|---|
| h. m. s. | | h. m. s. |
| 5 18 48 | = | 23 52 30.5 |
| 6 51 22.5 | = | 1 25 20 |

REDUCTION BY METHOD OF SINGLE ALTITUDES.

[W. UPTON, computer.]

| | h. m. s. | |
|---|---|---|
| 202 slow | 10 1 31.2 | Greenwich sidereal time. |
| 1340 fast | 8 4.4 | Greenwich mean time. |

## § I. THE METEOROLOGY OF CAROLINE ISLAND.

By MR. WINSLOW UPTON.

### *DESCRIPTION OF INSTRUMENTS AND STATION.*

The meteorological record kept at Caroline Island covers the period of two weeks extending from April 25 to May 9. During this time frequent observations were made with the ordinary meteorological instruments, and with special radiation apparatus furnished through the courtesy of the Chief Signal Officer. The following was the meteorological outfit :

1 small instrument shelter (window pattern).
1 aneroid barometer (HOTTINGER, 3241).
1 maximum thermometer.
2 minimum thermometers.
6 ordinary thermometers.
1 BROWNING'S rain-band spectroscope.
2 pair conjugate thermometers.
2 pair VIOLLE'S conjugate bulbs.
1 ROBINSON'S anemometer (belonging to the U. S. S. *Hartford*).

The proper exposure of the meteorological instruments received special attention. The shelter was erected, with the open side facing the south, upon a wooden support about 4 feet high, under the shade of a high cocoanut tree, there being several other trees in the immediate vicinity. The roof sloped towards the north, and after April 29 was surmounted by an additional roof raised about 4 inches above the first. The north side of the shelter contained a door, which was frequently open. This arrangement of the shelter proved very satisfactory. The whole shelter was shielded from the direct rays of the sun, except for a short time soon after sunrise, by the branches of the trees, and the rays which came through these branches during the heated portion of the day fell upon the upper roof. The important condition of a free circulation of air about the instruments was also secured, since the branches of the trees were from 10 to 20 feet above the shelter, allowing the wind to blow beneath them. Three sides of the shelter were made of open louvre work, while the fourth was wholly open. In order to test, by actual observation, the success of the above method of exposure, a series of readings was made of the dry-bulb thermometer, and of a thermometer whirled rapidly in the open air. The readings were made under various conditions during several days, and are given at the end of this report. They show that the readings of the dry-bulb thermometer may be accepted without correction as giving closely the temperature of the air.

Within this shelter were placed the maximum, minimum, dry-bulb, and wet-bulb thermometers, and beneath it, one foot above the grass, a thermometer adapted for measuring the minimum temperature at night close to the ground. The bulbs within the shelter were elevated 5 feet above the ground. The aneroid barometer was of the GOLDSCHMID pattern, and proved to be a good instrument. It was generally kept in the house, but during the frequent observations on April 29 and May 6, was for convenience placed in the shade in the open air or in the instrument shelter. Comparisons between the readings of this barometer and the mercurial barometer furnished Mr. PRESTON by the United States Coast and Geodetic Survey were frequently made, and are given at the end of this report. From them a constant correction of + 0.104 inch to the aneroid barometer was derived, and has been used in the reduction of the readings. The elevation of the instrument was about 10 feet above the level of the sea.

The anemometer was mounted on an iron rod, 9 feet 7 inches above the ground, in a large open space to which the wind had good access, especially from the north and east, the only direction in which the wind was observed to blow during the period of observation.

The rain-band spectroscope was read occasionally only. Its readings at the different observations were nearly the same, as will be seen from the record given at the end of this report. In damp insular positions in the tropics the instrument seems to give about the same indications from time to time, and therefore is of less value as a hygrometer than in the temperate zone.

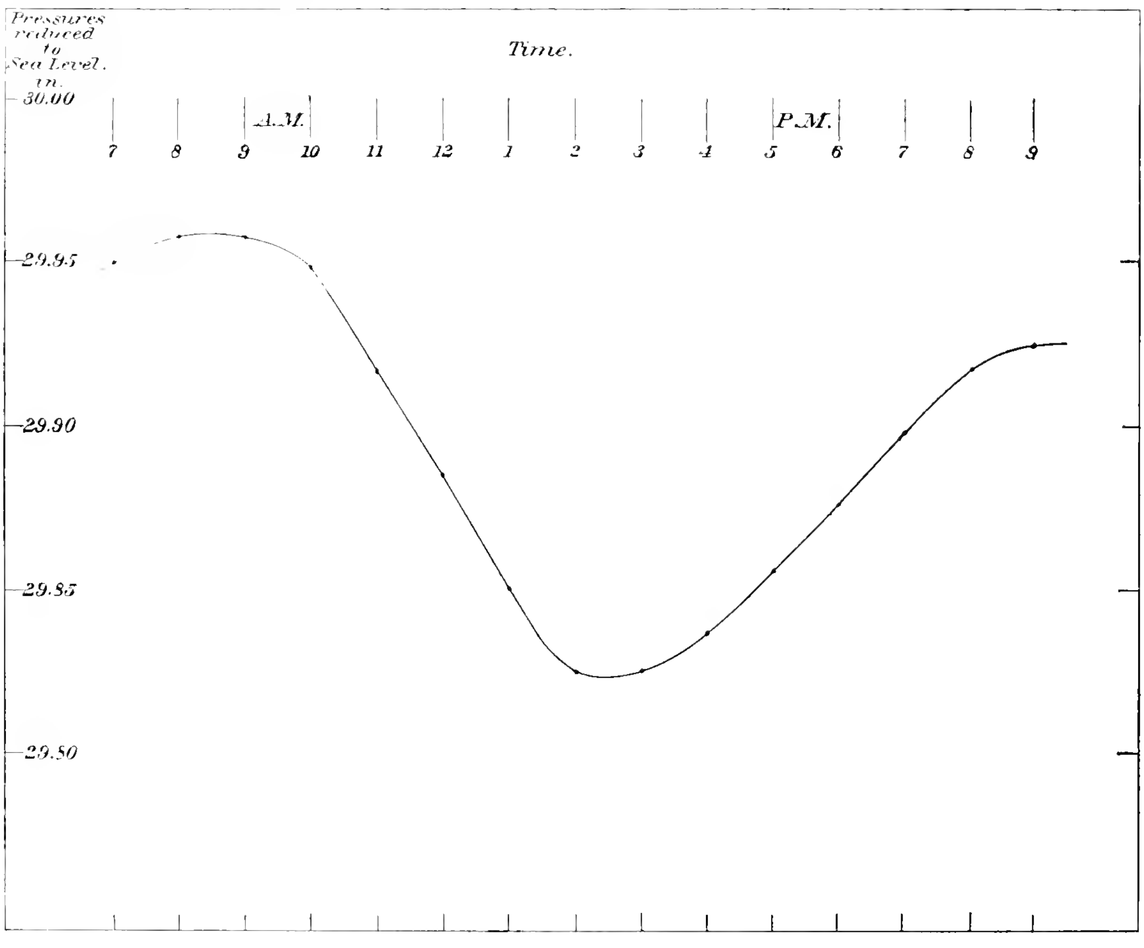
The instruments were read daily at frequent intervals between 6 a. m. and 9 p. m. As the principal object of the observations was to furnish a basis of comparison for those made in connection with the eclipse, the record is especially full between the hours of 10 a. m. and 2 p. m. The observations are given in detail at the end of this report. From them may be gleaned the following facts bearing upon the meteorology of the island.

### *GENERAL WEATHER CONDITIONS.*

With the exception of one day, May 4, the conditions were uniform, and characterized by fair weather with cumulus clouds passing rapidly over the sky, giving rise to frequent but slight showers. Upwards of twenty of these showers were noted during the two weeks, the rainfall at each being small. The sky was sometimes clear for several hours, especially in the middle of the day and in the early evening. The clouds observed were almost wholly of the cumulus class, cirro-stratus being also seen occasionally. The only weather disturbance occurred on May 4,

**Fig. 15.**

MEAN BAROMETRIC CURVE, APRIL 25–MAY 6.



when it rained steadily from about midnight to 9.50 a. m.; it remained cloudy until afternoon, when the sky gradually cleared. Following this day, the clouds were more frequent than they had been for several preceding days, the wind stronger, the humidity somewhat greater, and showers more frequent.

### BAROMETRIC PRESSURE.

The barometric pressure was markedly uniform from day to day, the diurnal movement being clearly apparent. The following table contains the hourly barometric readings between April 25 and May 6, reduced for temperature and elevation. Values in brackets are interpolated for the purpose of obtaining the mean values.

*Reduced barometric readings.*

| Hour. | April 25. | April 26. | April 27. | April 28. | April 29. | April 30. | May 1. | May 2. | May 3. | May 4. | May 5. | May 6. | Mean. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A. M. | | | | | | | | | | | | | |
| 7.00 | 29.95 | 29.99 | 29.96 | 29.93 | 29.91 | 29.89 | 29.92 | 29.94 | 29.97 | [30.03] | 29.99 | 29.98 | 29.955 |
| 8.00 | .97 | .98 | .97 | .95 | .93 | .90 | .93 | .94 | .98 | 30.03 | 30.00 | .98 | .963 |
| 9.00 | .97 | .99 | .98 | .95 | .92 | [.90] | .93 | .95 | .97 | .06 | 29.99 | .99 | .967 |
| 10.00 | .97 | .99 | .97 | .93 | .90 | .89 | .92 | .94 | .97 | .03 | .99 | .98 | .957 |
| 11.00 | .92 | .96 | .95 | .91 | .86 | .87 | .90 | .92 | .93 | .01 | .96 | .94 | .928 |
| 12.00 | .93 | .93 | .92 | .87 | .84 | .81 | .87 | .87 | .89 | 30.00 | .94 | .94 | .903 |
| P. M. | | | | | | | | | | | | | |
| 1.00 | .90 | .91 | .88 | .85 | .75 | .83 | .85 | .85 | .85 | 29.96 | .90 | .89 | .868 |
| 2.00 | .87 | .88 | .85 | .82 | .75 | .80 | .82 | .83 | [.83] | .92 | .89 | .87 | .844 |
| 3.00 | .86 | .87 | .83 | .80 | .76 | .79 | .81 | .83 | [.83] | .90 | .88 | .87 | .836 |
| 4.00 | .87 | .88 | .84 | .80 | [.78] | .79 | [.83] | .84 | [.84] | [.90] | [.89] | .88 | .845 |
| 5.00 | .89 | .90 | .85 | .83 | [.80] | .81 | [.85] | .87 | [.85] | .90 | [.90] | .90 | .862 |
| 6.00 | .89 | .91 | .85 | .84 | [.82] | .83 | [.87] | [.89] | .86 | .92 | .91 | .91 | .875 |
| 7.00 | - - | .95 | .89 | - - | - - | - - | - - | - - | .91 | - - | - - | - - | - - |
| 8.00 | - - | .98 | .90 | - - | - - | - - | - - | - - | .93 | - - | - - | - - | - - |
| 9.00 | .96 | .98 | .90 | .91 | .87 | .90 | .93 | .94 | .97 | .98 | .94 | .96 | .938 |

It will be seen from this table that a barometric maximum occurred on each day at about 9 a. m., and a minimum at about 3 p. m. No regular barometric observations were made at night after 9 p. m., but Messrs. PRESTON and BROWN, in connection with their observations, read a mercurial barometer occasionally during the night. From these observations it is learned that a second maximum occurred at about 9 p. m., and a second minimum at about 3 a. m.

The table also shows indications of a barometric period covering several days, a minimum occurring April 29, and a maximum May 4. The latter was accompanied by the heavy rain-storm elsewhere mentioned.

### AIR TEMPERATURE.

The thermometric readings show a similarity from day to day, and also, as would be expected from an insular station, a small daily range averaging 9°.3. The highest reading noted was 89°.3 on April 28; the lowest 72°.4 during the rain-storm on the morning of May 4. The minimum thermometer placed on the ground gave readings nearly identical with those of the minimum thermometer in the instrument shelter.

The daily maximum temperature occurred at very nearly noon, and the minimum at about 6 a. m.

### HUMIDITY.

The relative humidity was always great, ranging from an average of 70 per cent. in the middle of the day to 84 per cent. in the early morning. The lowest value observed was 61 per cent. at 11.30 a. m., May 2.

RAINFALL.

In order to measure approximately the rainfall a gauge was improvised with the aid of a tin can of uniform diameter. The frequent showers gave in general an inappreciable amount of rain, though some of them gave small amounts, one-tenth of an inch or over. The meteorological summary gives the record of the rainfall, from which it will be seen that the total amount during the two weeks was about 8 inches. More than half of this fell in the rain-storm of May 4, when it rained hard and steadily from midnight to 9.50 a. m.

WIND.

The observations of the direction and velocity of the wind give some interesting results. The former was almost always noted as east or northeast, and was at no time observed to be from any other quarter than between north and east. The island is situated in the region of the southeast trades, which makes it noteworthy that not a single record gives a direction south of east.

The table of wind velocities on page — gives in detail the results of the anemometrical observations. From this it will be seen that there is no indication sufficiently marked of any diurnal change in the wind's velocity. It is, however, apparent that there was a decrease of velocity from the beginning of the series to May 2, and an increase to May 7. These dates follow the dates of minimum and maximum pressure mentioned above by an interval of about two days, but the series is for too short a period of time to warrant the drawing of any inferences as to their relation. Indeed, it may be said that the indications of periodicity in both these cases may be only accidental, and not real indications of a progressive movement. It would take a longer continued series of observations to decide the question, and therefore the above are mentioned as only possibilities which these observations suggest.

The average hourly velocity of the wind was 6.05 miles; the largest total movement in twenty-four hours was 212.3 miles, from 7 a. m. May 7 to 7 a. m. May 8; the least 59.2, between the same hours May 4 and 5. The highest velocity observed was on April 30, during the passage of a squall which was characterized by wind without rain. At 12.35 p. m. the anemometer registered 1 mile in $3^m$ $40^s$, the equivalent of 16 miles an hour. The wind usually increased during the passage of the heavier showers.

*METEOROLOGICAL OBSERVATIONS BETWEEN APRIL 25 AND MAY 9, 1883.*

The observations given below were made with the following instruments:

Aneroid barometer, HOTTINGER, 3241.

Dry-bulb thermometer, GREEN, 799, stem graduated.

Wet-bulb thermometer, GREEN, 797, stem graduated.

Maximum thermometer, GREEN, 725, stem graduated.

Minimum thermometer, GREEN, 710, stem graduated.

Minimum thermometer for use at ground, HICKS, 5521, stem graduated.

ROBINSON'S anemometer, GREEN, 111.

The readings of these instruments are given exactly as recorded, with the following exceptions:

The readings of the maximum thermometer have been corrected by the amount— 0°.5, determined by thirty-seven comparisons with the dry bulb made April 27–30.

The readings of the minimum thermometer, GREEN, 710, have been corrected by the value + 0°.4, determined by sixty-two similar comparisons; those of the minimum thermometer, HICKS, 5521, by + 2°.0, determined by forty similar comparisons. The large correction to the latter was due to a bubble in the instrument, which was several times removed, but as often formed again.

The readings of the aneroid barometer have been reduced by applying the corrections for instrumental error, temperature, and elevation. These have been obtained as follows:

REDUCTION OF OBSERVATIONS MADE WITH ANEROID BAROMETER, HOTTINGER, 3241.

*Comparisons between aneroid barometer*, HOTTINGER, 3241, *and mercurial barometer*, GREEN, 1936.

| Date. | Hour. | 3241. t. | 3241. Reading. | 1936. t. | 1936. Reading. | Readings corrected for temperature. 3241. | Readings corrected for temperature. 1936. | Correction to 3241. |
|---|---|---|---|---|---|---|---|---|
| | | ° | *in.* | | *in.* | *in.* | *in.* | *in.* |
| April 25 | 10.40 a. m. | 85 | 29.927 | 91.4 | 30.123 | 29.84 | 29.96 | + 0.12 |
| 27 | 7.00 a. m. | 83 | .927 | 81.7 | .031 | .85 | .89 | .04 |
| 27 | 2.00 p. m. | 85 | .827 | 92.6 | .037 | .74 | .86 | .12 |
| 27 | 9.00 p. m. | 84 | .873 | 81.2 | .032 | .79 | .89 | .10 |
| 28 | 2.30 p. m. | 86 | .778 | 98.7 | .002 | .69 | .82 | .13 |
| 28 | 9.00 p. m. | 83 | .876 | 82.4 | .038 | .80 | .89 | .09 |
| 30 | 9.00 p. m. | 84 | .873 | 81.7 | .038 | .79 | .90 | .11 |
| May 1 | 11.00 a. m. | 85 | .875 | 95.6 | .080 | .79 | .90 | .11 |
| 6 | 8.00 a. m. | 83 | .949 | 86.1 | .120 | .87 | .97 | .10 |
| 6 | 9.00 p. m. | 82 | .922 | 81.7 | .081 | .84 | .94 | .10 |
| 7 | 6.00 p. m. | 84 | .813 | 81.7 | .020 | .73 | .88 | .15 |
| 7 | 9.00 p. m. | 83 | .887 | 81.2 | .046 | .81 | .90 | .09 |
| 8 | 7.00 a. m. | 81 | .870 | 80.8 | .025 | .80 | .89 | .09 |
| Mean | | | | | | | | + 0.104 |

*Temperature corrections to barometer*, HOTTINGER, 3241.

[Furnished by maker.]

| t. | Corr. |
|---|---|
| ° | *in.* |
| 76 | — 0.06 |
| 80 | — 0.07 |
| 84 | — 0.085 |
| 88 | — 0.10 |
| 92 | — 0.11 |

Elevation of instrument above sea-level, 10 feet. Reduction to sea-level, + 0.01 inch.

Combining these reductions we have the following table by which the barometer readings in the column "Reduced reading" are obtained from the observed readings:

| t. | Reduction. |
|---|---|
| ° | *in.* |
| 76 | + 0.054 |
| 80 | .044 |
| 84 | .029 |
| 88 | .014 |
| 92 | + 0.004 |

*Comparisons between dry bulb thermometers,* GREEN, 799, *placed in the instrument shelter, and* GREEN, 811, *read after being swung rapidly through the air.*

[These comparisons were made on different days between April 25 and May 2. The swinging of GREEN, 811, was repeated several times until it seemed certain that it had assumed its true reading. The differences only between the readings are given. The instrumental corrections to both of these thermometers are 0.0.]

811—799.

| I. Before extra roof was placed upon shelter. | | II. After extra roof was placed upon shelter. | | III. During a period of calm, May 2. | |
|---|---|---|---|---|---|
| + | — | + | — | + | — |
| ° | ° | | ° | ° | ° |
| 0.6 | 0.3 | 0.0 | 0.4 | 0.5 | 0.7 |
| .3 | .3 | .6 | .1 | | .3 |
| .2 | .1 | .2 | .3 | | .8 |
| .0 | 1.0 | .0 | .2 | | .1 |
| .0 | .8 | .2 | .1 | +0.5 | — 1.9 |
| .4 | .3 | .0 | | Sum — 1.4 | |
| .0 | .6 | .0 | | Mean — 0°.3 | |
| | .2 | .3 | | | |
| | .4 | .2 | | | |
| | 1.7 | .1 | | | |
| | .9 | .4 | | | |
| | .3 | .0 | | | |
| | 1.2 | + 2.0 | — 1.1 | | |
| + 1.5 | — 8.1 | + 0.9 | | | |
| Sum —6.6. | | + 0.1 | | | |
| Mean —0.3. | | | | | |

If we assume, as is usual, that the whirled thermometer gives a close approximation to the true air temperature, the above comparison shows what correction should be applied to the thermometer in the instrument shelter. It will be seen that the effect of placing a double roof upon the shelter was to diminish this correction, the correction becoming almost inappreciable except in the extreme case on May 2, when there was no wind and the air was accordingly stagnant in the shelter. As a result of these comparisons, it was decided to adopt the readings of the dry-bulb thermometer within the shelter without any correction for the air temperature.

APRIL 25, 1883.

| Hour. | Barometer. t. | Barometer. Observed reading. | Barometer. Reduced reading. | Thermometer. Dry. | Thermometer. Wet. | Rel. hum. | Anemometer. | Wind. | Weather. | Clouds. |
|---|---|---|---|---|---|---|---|---|---|---|
| A. M. | | | | | | | | | | |
| 6.00 | - - | - - - - - | - - - - | 79.0 | 76.3 | 88 | - - - | NE. | Clear. | 2 cum. in horizon. |
| 7.00 | 82 | 29.916 | 29.95 | 81.9 | 78.0 | 82 | - - - | NE | Clear. | 2 cum. in horizon. |
| 8.00 | 83 | .934 | .97 | 84.5 | 79.2 | 78 | - - - | NE | Clear. | 1 cum. in horizon. |
| 9.00 | 84 | .942 | .97 | 86.3 | 81.7 | 79 | - - - | NE | Clear. | 1 cum. |
| 10.00 | 84 | .945 | .97 | 86.5 | 79.7 | 71 | - - - | NE | Clear. | 2 cum. |
| 11.00 | 87 | .897 | .92 | 86.2 | 80.8 | 76 | - - - | NE. | Clear. | 2 cum. |
| 12.00 | 85 | .900 | .93 | 86.0 | 79.6 | 74 | - - - | NE. | Clear. | 1 cum. |
| P. M. | | | | | | | | | | |
| 1.00 | 85 | .877 | .90 | 87.5 | 80.2 | 71 | - - - | NE. | Clear. | 2 cum. |
| 2.00 | 86 | .848 | .87 | 87.5 | 80.2 | 71 | - - - | NE. | Clear. | 1 cum. |
| 3.00 | 86 | .838 | .86 | 86.0 | 80.0 | 75 | - - - | E. | Clear. | 1 cum. |
| 4.00 | 85 | .847 | .87 | 84.9 | 79.2 | 74 | - - - | NE. | Clear. | 2 cum. |
| 5.00 | 85 | .863 | .89 | 83.7 | 78.7 | 81 | 237.0 | NE. | Clear. | 2 cum. |
| 6.00 | 85 | .868 | .89 | 82.7 | 78.0 | 78 | 246.3 | NE. | Cloudy. | 8 cum. and str. |
| 9.00 | 81 | .935 | .96 | 82.2 | 77.8 | 82 | 266.9 | NE. | Clear. | 1 cum. |

*Miscellaneous.*—Minimum, 78.2. Minimum at ground, 76.6. Maximum, 88.2.

6.00 a. m. Double rainbow in the west.

8.30 p. m. Zodiacal light plainly seen in the west, but with limits ill defined. It extended about 30° in altitude, 60° in azimuth.

9.10 p. m. Moon made shadow bands through the clouds above it, similar to those frequently made by the sun.

APRIL 26, 1883.

| Hour. | t. | Barometer. Observed reading. | Barometer. Reduced reading. | Thermometer. Dry. | Thermometer. Wet. | Rel. hum. | Anemometer. | Wind. | Weather. | Clouds. |
|---|---|---|---|---|---|---|---|---|---|---|
| A. M. | | | | | | | | | | |
| 7.00 | 83 | 29.955 | 29.99 | 82.8 | 77.8 | 80 | 331.9 | NE. | Fair. | 3 cum. |
| 8.00 | 83 | .945 | .98 | 85.0 | 79.8 | 80 | 339.0 | NE. | Clear. | 2 cum. |
| 9.00 | 84 | .960 | .99 | 83.0 | 77.7 | 77 | 347.4 | NE. | Clear. | 2 cum. |
| 10.00 | 84 | .969 | .99 | 86.0 | 79.7 | 74 | 352.6 | NE. | Fair. | 4 cum. |
| 11.00 | 84 | .932 | .96 | 87.2 | 79.7 | 70 | 360.3 | NE. | Fair. | 3 cum. |
| 12.00 | 84 | .902 | .93 | 87.2 | 79.8 | 70 | 367.2 | NE. | Fair. | 3 cum. |
| P. M. | | | | | | | | | | |
| 1.00 | 84 | .877 | .91 | 86.2 | 78.7 | 70 | 374.8 | NE. | Clear. | 1 cum. |
| 2.00 | 85 | .858 | .88 | 85.8 | 78.6 | 73 | 382.4 | NE. | Fair. | 3 cum. |
| 3.00 | 85 | .848 | .87 | 85.8 | 78.8 | 73 | 389.3 | NE. | Fair. | 3 cum. |
| 4.00 | 85 | .855 | .88 | 84.9 | 79.0 | 74 | 393.6 | NE. | Fair. | 4 cum. |
| 5.00 | 84 | .872 | .90 | 83.9 | 78.3 | 77 | 396.3 | NE. | Fair. | 3 cum. |
| 6.00 | 84 | .883 | .91 | 82.2 | 77.2 | 79 | 402.2 | NE. | Fair. | 5 cum. |
| 7.00 | 84 | .925 | .95 | 75.5 | 73.5 | 89 | 408.1 | NE. | Rain. | 10 nim. |
| 8.00 | 82 | .945 | .98 | 78.0 | 77.8 | 100 | 410.3 | NE. | Cloudy. | 9 cum. |
| 9.00 | 82 | .944 | .98 | 79.2 | 76.3 | 88 | 418.1 | NE. | Cloudy. | 10 str. |

*Miscellaneous.*—Minimum, 80.8 at 7.00 a. m.; 75.1 at 9.00 p. m. Minimum at ground, 81.1. Maximum, 87.8. Light showers at 10.05 a. m., 2.15, 4.05 p. m.
Heavy showers in the evening after 6.30 p. m. Rainfall, 0.3.

APRIL 27, 1883.

| Hour. | t. | Barometer. Observed reading. | Barometer. Reduced reading. | Thermometer. Dry. | Thermometer. Wet. | Rel. hum. | Anemometer. | Wind. | Weather. | Clouds. |
|---|---|---|---|---|---|---|---|---|---|---|
| A. M. | | | | | | | | | | |
| 6.00 | 81 | 29.913 | 29.95 | 81.0 | 76.8 | 82 | 476.0 | NE. | Fair. | 2 cum., 2 cir. str. and cir. cum. |
| 7.00 | 83 | .927 | .96 | 82.0 | 77.2 | 80 | 484.4 | NE. | Fair. | 2 cum., 2 cir. str. and cir. cum. |
| 8.00 | 83 | .940 | .97 | 78.8 | 75.9 | 89 | 494.5 | E. | Rain. | 9 cum. |
| 9.00 | 83 | .947 | .98 | 84.6 | 79.2 | 78 | 502.1 | NE. | Fair. | 3 cum., heavy nim. in north. |
| 10.00 | 83 | .935 | .97 | 84.5 | 79.2 | 81 | 511.8 | NE. | Fair. | 4 cum. |
| 11.00 | 83 | .914 | .95 | 85.2 | 79.4 | 74 | 519.4 | NE. | Fair. | 3 cum. and cir. str. |
| 12.00 | 84 | .887 | .92 | 87.2 | 80.9 | 74 | 525.8 | E. | Fair. | 3 cum. and cir. str. |
| P. M. | | | | | | | | | | |
| 1.00 | 84 | .850 | .88 | 86.2 | 79.2 | 72 | 532.7 | E. | Fair. | 3 cum. and cir. str. |
| 2.00 | 85 | .827 | .85 | 86.7 | 79.7 | 71 | 539.0 | E. | Clear. | 2 cum. and cir. str. |
| 3.00 | 85 | .810 | .83 | 85.0 | 78.2 | 72 | 544.7 | E. | Fair. | 3 cum. and cir. str. |
| 4.00 | 85 | .812 | .84 | 84.3 | 78.2 | 73 | 549.9 | NE. | Fair. | 3 cum. and cir. str. |
| 5.00 | 85 | .822 | .85 | 82.9 | 77.7 | 77 | 555.0 | NE. | Fair. | 3 cum. and cir. str. |
| 6.00 | 85 | .829 | .85 | 82.0 | 77.6 | 82 | 559.6 | NE. | Fair. | 4 cum. and cir. str. |
| 7.00 | 84 | .861 | .89 | 81.8 | 77.4 | 81 | 564.3 | NE. | Clear. | 1 cum. in horizon. |
| 8.00 | 84 | .869 | .90 | 81.8 | 76.6 | 80 | 568.9 | NE. | Clear. | 1 cum. |
| 9.00 | 84 | .873 | .90 | 81.6 | 77.0 | 80 | 575.3 | NE. | Clear. | 1 cum. |

*Miscellaneous.*—Minimum, 78.1. Maximum, 88.3. Shower, 7.40–8.00 a. m.; inappreciable.
7.30 p. m., zodiacal light seen—an arch in west, 25° high and 40° broad, with limits poorly defined.

APRIL 28, 1883.

| Hour. | Barometer. t. | Barometer. Observed reading. | Barometer. Reduced reading. | Thermometer. Dry. | Thermometer. Wet. | Rel. hum. | Anemometer. | Wind. | Weather. | Clouds. |
|---|---|---|---|---|---|---|---|---|---|---|
| A. M. | | | | | | | | | | |
| 6.00 | 82 | 29.879 | 29.91 | 80.8 | 76.7 | 83 | 627.1 | E. | Clear. | 2 cum. and cir. str. |
| 7.00 | 82 | .895 | .93 | 79.9 | 76.3 | 85 | 632.1 | E. | Fair. | 4 cum. |
| 8.00 | 82 | .912 | .95 | 83.0 | 78.5 | 80 | 636.6 | E. | Fair. | 3 cum. |
| 9.00 | 82 | .913 | .95 | 85.0 | 78.8 | 82 | 643.8 | E. | Clear. | 2 cum. in north. |
| 10.00 | 83 | .902 | .93 | 85.0 | 80.0 | 80 | 650.9 | NE. | Clear. | 1 cum. and cir. str. |
| 10.35 | 83 | .887 | .92 | 85.9 | 79.0 | 72 | - - - | E. | Clear. | 1 cir. str. |
| 11.00 | 84 | .877 | .91 | 86.5 | 78.7 | 67 | 654.9 | NE. | Clear. | 1 cir. str. |
| 11.30 | 84 | .862 | .89 | 86.8 | 79.7 | 69 | 656.8 | NE. | Clear. | 1 cum. in horizon. |
| 12.00 | 84 | .839 | .87 | 87.2 | 80.2 | 72 | 658.5 | NE. | Clear. | 1 cum. in horizon. |
| P. M. | | | | | | | | | | |
| 12.30 | 84 | .832 | .86 | 87.8 | 81.0 | 73 | 660.2 | E. | Clear. | 2 cum. |
| 1.00 | 84 | .820 | .85 | 87.0 | 80.1 | 72 | 661.4 | E. | Clear. | 2 cum. |
| 1.30 | 85 | .805 | .83 | 87.0 | 80.7 | 75 | 663.1 | NE. | Clear. | 2 cum. |
| 2.00 | 85 | .798 | .82 | 87.3 | 80.3 | 71 | 664.2 | NE. | Fair. | 4 cum. |
| 2.30 | 86 | .778 | .80 | 86.0 | 79.0 | 72 | 666.7 | E. | Fair. | 4 cum. |
| 3.00 | 86 | .777 | .80 | 87.0 | 80.1 | 72 | 669.9 | E. | Fair. | 4 cum. |
| 3.30 | 86 | .775 | .80 | 85.2 | 78.0 | 72 | 672.2 | E. | Clear. | 2 cum. |
| 4.00 | 86 | .779 | .80 | 85.5 | 78.0 | 71 | 675.4 | E. | Clear. | 1 cum. |
| 4.30 | 86 | .788 | .81 | 84.0 | 77.8 | 74 | 678.2 | E. | Clear. | 1 cum. |
| 5.00 | 85 | .800 | .83 | 83.2 | 77.2 | 74 | 681.6 | E. | Clear. | 2 cum. |
| 6.00 | 85 | .815 | .84 | 82.4 | 77.2 | 79 | 687.4 | E. | Fair. | 3 cum. |
| 9.00 | 83 | .876 | .91 | 82.0 | 77.3 | 80 | 708.9 | E. | Clear. | 1 cum. |

*Miscellaneous.*—Minimum, 79.2. Minimum at ground, 79.5. Maximum, 89.3.

Shower about 10 p.m., giving 0.02 inch of rain by estimation. 6.30 a.m., fine alternate dark and light streaks extending completely across the sky through the zenith; sun behind heavy cumuli.

APRIL 29, 1883.

| Hour. | Barometer. t. | Barometer. Observed reading. | Barometer. Reduced reading. | Thermometer. Dry. | Thermometer. Wet. | Rel. hum. | Anemometer. | Wind. | Weather. | Clouds. |
|---|---|---|---|---|---|---|---|---|---|---|
| A. M. | | | | | | | | | | |
| 6.30 | 83 | 29.862 | 29.89 | 81.4 | 76.6 | 78 | 767.4 | NE. | Fair. | 3 cum. and cir. str. |
| 7.00 | 82 | .872 | .91 | 82.2 | 77.2 | 79 | 770.9 | NE. | Fair. | 3 cum. and cir. str. |
| 8.00 | 82 | .898 | .93 | 84.3 | 78.3 | 73 | 777.3 | NE. | Clear. | 2 cum. |
| 8.30 | - - | - - - - | - - - - | 85.5 | 79.0 | 73 | 780.3 | NE. | Clear. | 2 cum. |
| 9.00 | 83 | .885 | .92 | 85.9 | 79.0 | 72 | 783.0 | NE. | Clear. | 2 cum. |
| 9.30 | 83 | .882 | .91 | 86.1 | 79.7 | 75 | 785.6 | NE. | Clear. | 2 cum. |
| 10.00 | 83 | .872 | .90 | 87.1 | 80.2 | 72 | 788.6 | NE. | Clear. | 2 cum. |
| 10.30 | 84 | .865 | .89 | 86.1 | 79.1 | 72 | 791.3 | NE. | Fair. | 3 cum. |
| 11.00 | 86 | .841 | .86 | 87.1 | 79.5 | 68 | 794.3 | NE. | Clear. | 2 cum. |
| 11.30 | 86 | .819 | .84 | 87.8 | 80.5 | 73 | 797.2 | NE. | Clear. | 1 cum. |
| 12.00 | 86 | .815 | .84 | 87.9 | 80.0 | 70 | 800.2 | NE. | Clear. | 1 cum. |
| P. M. | | | | | | | | | | |
| 12.30 | 86 | .791 | .81 | 88.0 | 80.2 | 70 | 802.9 | NE. | Clear. | 1 cum. |
| 1.00 | 92 | .743 | .75 | 87.0 | 80.0 | 72 | 805.9 | NE. | Fair. | 4 cum. |
| 1.30 | 89 | .748 | .76 | 87.7 | 80.5 | 73 | 807.6 | NE. | Clear. | 2 cum. |
| 2.00 | 89 | .740 | .75 | 87.7 | 80.3 | 73 | 810.9 | NE. | Clear. | 2 cum. |
| 2.30 | 88 | .741 | .76 | 87.5 | 80.0 | 71 | 812.3 | NE. | Clear. | 2 cum. |
| 3.00 | 88 | .745 | .76 | 87.0 | 79.9 | 72 | 814.5 | NE. | Clear. | 2 cum. |
| 3.30 | 87 | .748 | .77 | 86.1 | 79.2 | 72 | 816.8 | NE. | Fair. | 3 cum. |
| 9.00 | 83 | .838 | .87 | 82.3 | 76.8 | 76 | 855.7 | E. | Clear. | 1 cum. |

*Miscellaneous.*—Minimum, 77.7. Minimum at ground, 77.8. Maximum, 88.4.

APRIL 30, 1883.

| Hour. | Barometer. t. | Barometer. Observed reading. | Barometer. Reduced reading. | Thermometer. Dry. | Thermometer. Wet. | Rel. hum. | Anemometer. | Wind. | Weather. | Clouds. |
|---|---|---|---|---|---|---|---|---|---|---|
| A. M. | | | | | | | | | | |
| 6.00 | 83 | 29.835 | 29.87 | 81.0 | 76.8 | 82 | 921.1 | NE. | Clear. | 2 cum. and cir. str. |
| 7.00 | 82 | .858 | .89 | 82.8 | 79.0 | 83 | 925.3 | NE. | Clear. | 2 cum. |
| 7.30 | 83 | .870 | .90 | 84.0 | 79.5 | 82 | 927.5 | NE. | Clear. | 1 cum. |
| 8.00 | 83 | .869 | .90 | 84.1 | 78.8 | 80 | 929.5 | NE. | Clear. | 2 cum. |
| 9.00 | - - | - - - - | - - - - | 85.9 | 79.2 | 72 | 935.1 | NE. | Clear. | 2 cum. |
| 9.30 | 84 | .883 | .91 | 86.2 | 79.6 | 72 | 938.0 | NE. | Fair. | 4 cum. |
| 10.00 | 85 | .868 | .89 | 85.0 | 79.2 | 75 | 939.6 | NE. | Fair. | 5 cum. |
| 10.30 | 85 | .864 | .89 | - - - | - - - | - - - | - - - | NE. | Clear. | 2 cum. |
| 11.00 | 86 | .818 | .87 | 86.7 | 80.0 | 73 | 944.0 | NE. | Clear. | 1 cum. |
| 11.30 | 86 | .832 | .85 | 86.9 | 79.9 | 72 | 945.7 | NE. | Clear. | 1 cum. |
| 12.00 | 86 | .823 | .84 | 86.8 | 80.0 | 73 | 947.9 | NE. | Clear. | 2 cum. |
| P. M. | | | | | | | | | | |
| 1.00 | 86 | .805 | .83 | 83.5 | 78.8 | 78 | 958.5 | NE. | Fair. | 3 cum. |
| 2.00 | 86 | .783 | .80 | 84.8 | 79.1 | 75 | 968.3 | NE. | Clear. | 1 cum. |
| 3.00 | 88 | .775 | .79 | 81.8 | 78.3 | 75 | 978.2 | NE. | Clear. | 1 cum. in horizon. |
| 3.30 | 87 | .764 | .78 | 84.6 | 78.0 | 73 | 981.5 | NE. | Clear. | 1 cum. in horizon. |
| 4.00 | 86 | .770 | .79 | 83.8 | 77.8 | 75 | 984.8 | NE. | Clear. | 1 cum. in horizon. |
| 4.30 | 86 | .785 | .81 | 83.2 | 77.2 | 75 | 987.2 | NE. | Clear. | 1 cum. in horizon. |
| 5.00 | 85 | .790 | .81 | 82.9 | 77.0 | 75 | 0.1 | NE. | Clear. | 1 cum. in horizon. |
| 6.00 | 86 | .806 | .83 | 82.0 | 77.9 | 82 | 6.7 | NE. | Clear. | 1 cum. in horizon. |
| 9.00 | 84 | .873 | .90 | 82.0 | 77.6 | 82 | 20.8 | NE. | Clear. | 1 cum. in horizon. |

*Miscellaneous.*—Minimum, 79.5. Minimum at ground, 78.8. Maximum, 88.2.

Slight showers at 5.00, 8.00, 10.00 a. m., and 8.00 p. m.; inappreciable. 12.30—1.00 p. m., a wind squall passed over. At 12.35 the anemometer registered 1 mile in 3 minutes 40 seconds, which equals 16 miles an hour.

Solar shadow bands seen in the east just after sunset.

MAY 1, 1883.

| Hour. | Barometer. t. | Barometer. Observed reading. | Barometer. Reduced reading. | Thermometer. Dry. | Thermometer. Wet. | Rel. hum. | Anemometer. | Wind. | Weather. | Clouds. |
|---|---|---|---|---|---|---|---|---|---|---|
| A. M. | | | | | | | | | | |
| 6.30 | - - | - - - - | - - - - | 81.9 | 76.0 | 74 | 86.8 | NE. | Clear. | 1 cum. and cir. str. in horizon. |
| 7.00 | 82 | 29.887 | 29.92 | 82.8 | 76.7 | 75 | 90.2 | NE. | Clear. | 1 cum. and cir. str. in horizon. |
| 7.30 | 82 | .891 | .93 | 83.5 | 77.0 | 71 | 91.0 | NE. | Clear. | 1 cum. in horizon. |
| 8.00 | 82 | .899 | .93 | 84.3 | 77.8 | 71 | 97.9 | NE. | Clear. | 2 cum. |
| 8.30 | 83 | .907 | .94 | 85.5 | 77.6 | 69 | 101.4 | NE. | Clear. | 2 cum. |
| 9.00 | 83 | .897 | .93 | 85.6 | 78.4 | 73 | 105.0 | NE. | Clear. | 1 cum. and cir. str. |
| 9.30 | 84 | .900 | .93 | 85.7 | 78.0 | 71 | 109.1 | NE. | Clear. | 1 cum. and cir. str. |
| 10.00 | 84 | .888 | .92 | 86.0 | 77.7 | 68 | 113.0 | NE. | Clear. | 1 cum. in horizon. |
| 10.30 | - - | - - - - | - - - - | 86.6 | 77.9 | 67 | 117.3 | NE. | Clear. | 1 cum. in horizon. |
| 11.00 | 85 | .875 | .90 | 85.8 | 77.1 | 66 | 121.5 | NE. | Clear. | 1 cum. in horizon. |
| 12.00 | 85 | .847 | .87 | 86.5 | 78.0 | 67 | 129.2 | NE. | Clear. | 0 haze in horizon. |
| P. M. | | | | | | | | | | |
| 1.00 | 85 | .820 | .85 | 86.8 | 78.1 | 66 | 135.6 | NE. | Clear. | 1 cum. and cir. str. |
| 2.00 | 86 | .802 | .82 | 86.0 | 77.2 | 66 | 142.7 | NE. | Clear. | 1 cir. str. in south. |
| 3.00 | 86 | .789 | .81 | 85.1 | 77.2 | 67 | 149.4 | NE. | Clear. | 1 cir. str. in south and west. |
| 9.00 | 83 | .895 | .93 | 81.5 | 76.1 | 78 | 187.0 | NE. | Clear. | 1 cum. |

*Miscellaneous.*—Minimum, 80.2. Minimum at ground, 80.8. Maximum, 87.6.

MAY 2, 1883.

| Hour. | Barometer. | | | Thermometer. | | Rel. hum. | Anemometer. | Wind. | Weather. | Clouds. |
|---|---|---|---|---|---|---|---|---|---|---|
| | t. | Observed reading. | Reduced reading. | Dry. | Wet. | | | | | |
| A. M. | | | | | | | | | | |
| 6.30 | - - | - - - - - | - - - - | 81.6 | 76.0 | 78 | 246.8 | NE. | Fair. | 3 cum. |
| 7.00 | 82 | 29.902 | 29.94 | 82.0 | 75.5 | 72 | 250.3 | NE. | Clear. | 2 cum. |
| 8.00 | 82 | .909 | .91 | 84.0 | 76.2 | 67 | 258.1 | NE. | Clear. | 1 cum. |
| 9.00 | 83 | .915 | .95 | 84.8 | 76.7 | 68 | 265.2 | NE. | Clear. | 2 cum. |
| 10.00 | 83 | .910 | .94 | 86.0 | 76.8 | 66 | 270.7 | NE. | Clear. | 1 cum. |
| 10.30 | 84 | .900 | .93 | 87.3 | 78.4 | 65 | 272.4 | NE. | Clear. | 1 cum. |
| 11.00 | 84 | .887 | .92 | 87.0 | 78.0 | 66 | 273.6 | NE. | Clear. | 1 cum. |
| 11.30 | 85 | .870 | .89 | 87.8 | 77.5 | 61 | 274.8 | NE. | Clear. | 1 cum. |
| 12.00 | 85 | .850 | .87 | 87.8 | 78.9 | 66 | 276.6 | NE. | Clear. | 0. |
| P. M. | | | | | | | | | | |
| 12.30 | 86 | .832 | .85 | 87.4 | 78.0 | 62 | 277.9 | NE. | Clear. | 0. |
| 1.00 | 86 | .825 | .85 | 87.0 | 77.9 | 66 | 278.9 | NE. | Clear. | 0. |
| 2.00 | 86 | .807 | .83 | 87.1 | 78.0 | 66 | 279.7 | Calm. | Clear. | 0. |
| 2.30 | 87 | .802 | .82 | 86.7 | 78.0 | 67 | 280.0 | Calm. | Clear. | 0. |
| 3.00 | 86 | .805 | .83 | 84.5 | 76.2 | 67 | 280.5 | NE. | Clear. | 0. |
| 3.30 | 86 | .808 | .83 | 84.5 | 76.6 | 67 | 281.4 | NE. | Clear. | 0. |
| 4.00 | 86 | .817 | .84 | 84.0 | 76.0 | 68 | 282.1 | NE. | Clear. | 0. |
| 4.30 | 86 | .827 | .85 | 83.1 | 75.7 | 68 | 283.5 | NE. | Clear. | 0. |
| 5.00 | 85 | .845 | .87 | 82.7 | 75.6 | 73 | 284.7 | NE. | Clear. | 0. |
| 9.00 | 84 | .913 | .94 | 81.0 | 75.0 | 74 | 292.7 | NE. | Clear. | 1 cum. |

*Miscellaneous.*—Minimum, 80.2. Minimum at ground, 80.8. Maximum, 88.7.

MAY 3, 1883.

| Hour. | Barometer. | | | Thermometer. | | Rel. hum. | Anemometer. | Wind. | Weather. | Clouds. |
|---|---|---|---|---|---|---|---|---|---|---|
| | t. | Observed reading. | Reduced reading. | Dry. | Wet. | | | | | |
| A. M. | | | | | | | | | | |
| 7.00 | 80 | 29.930 | 29.97 | 81.5 | 76.0 | 78 | 311.0 | NE. | Clear. | 2 cum. |
| 7.30 | 81 | .937 | .98 | 82.8 | 75.2 | 70 | 312.3 | NE. | Clear. | 2 cum. |
| 8.00 | 81 | .942 | .98 | 83.5 | 76.2 | 71 | 313.8 | NE. | Clear. | 2 cum. |
| 8.30 | 82 | .940 | .98 | 85.0 | 77.4 | 67 | 315.6 | NE. | Clear. | 1 cum. |
| 9.00 | 82 | *.837 | .97 | 85.3 | 77.9 | 69 | 317.5 | NE. | Clear. | 1 cum. |
| 9.30 | 83 | .942 | .97 | 86.0 | 78.2 | 68 | 320.2 | NE. | Clear. | 1 cum. |
| 10.00 | 84 | .938 | .97 | 85.6 | 77.6 | 67 | 323.2 | NE. | Fair. | 3 cum. |
| 10.30 | 84 | .923 | .95 | 86.8 | 78.0 | 66 | 326.2 | E. | Clear. | 2 cum. |
| 11.00 | 85 | .908 | .93 | 87.5 | 79.0 | 67 | 329.2 | NE. | Clear. | 2 cum. |
| 11.30 | 85 | .877 | .90 | 86.2 | 77.2 | 65 | 332.5 | NE. | Clear. | 1 cum. |
| 12.00 | 85 | .862 | .89 | 86.9 | 78.0 | 66 | 335.7 | NE. | Clear. | 1 cum. in horizon. |
| P. M. | | | | | | | | | | |
| 12.30 | 85 | .836 | .86 | 86.0 | 77.5 | 68 | 338.0 | NE. | Clear. | 1 cum. in horizon. |
| 1.00 | 86 | .825 | .85 | 86.8 | 78.0 | 66 | 340.2 | E. | Clear. | 1 cum. in horizon. |
| 1.30 | 86 | .821 | .84 | 86.7 | 78.7 | 69 | 342.0 | E. | Clear. | 1 cum. in horizon. |
| 2.00 | - - | - - - - | - - - - | 86.5 | 78.5 | 69 | 344.2 | E. | Clear. | 1 cum. |
| 2.30 | 86 | .807 | .83 | 86.0 | 78.6 | 70 | 346.1 | E. | Fair. | 3 cum. |
| 6.00 | 86 | .838 | .86 | 82.9 | 77.7 | 80 | 363.2 | NE. | Cloudy. | 9 cum. and nim. |
| 7.00 | 84 | .885 | .91 | 77.2 | 75.0 | 90 | 374.1 | NE. | Cloudy. | 9 cum. and nim. |
| 8.00 | 84 | .902 | .93 | 77.5 | 75.5 | 90 | 382.3 | NE. | Rain. | 10 cum. |
| 9.00 | 84 | .937 | .97 | 78.0 | 75.3 | 88 | 386.8 | Calm. | Rain. | 10 cum. |

* Probably should be 29.937.

*Miscellaneous.*—Minimum, 76.2. Minimum at ground, 75.5. Maximum, 88.1.

Rain began at 6.00 p. m. Light showers in the evening, with occasional thunder and lightning. Rainfall measured on the 4th.

MAY 4, 1883.

| Hour. | Barometer. t. | Barometer. Observed reading. | Barometer. Reduced reading. | Thermometer. Dry. | Thermometer. Wet. | Rel. hum. | Anemometer. | Wind. | Weather. | Clouds. |
|---|---|---|---|---|---|---|---|---|---|---|
| A. M. | | | | | | | | | | |
| 7.00 | - - | - - - - - | - - - - - | 74.2 | 74.0 | 99 | 403.8 | NE. | Rain. | 10 nim. |
| 7.30 | 78 | 29.980 | 30.03 | - - - | - - - | - - | - - - | - - - | - - - - | |
| 8.00 | 79 | 29.988 | .03 | 75.8 | 74.2 | 95 | 409.2 | NE. | Rain. | 10 nim. |
| 9.00 | 79 | 30.010 | .06 | 76.2 | 75.2 | 96 | 414.5 | NE. | Rain. | 10 nim. |
| 10.00 | 79 | 29.986 | .03 | 76.2 | 74.5 | 93 | 423.6 | NE. | Cloudy. | 10 str. |
| 11.00 | 79 | .968 | .01 | 80.0 | 76.1 | 82 | 429.2 | NE. | Cloudy. | 10 str. |
| 12.00 | 80 | .960 | 30.00 | 81.8 | 75.8 | 75 | 435.6 | N. | Cloudy. | 10 str. |
| P. M. | | | | | | | | | | |
| 1.00 | 80 | .917 | 29.96 | 81.0 | 75.8 | 79 | 442.6 | N. | Cloudy. | 10 str. |
| 2.00 | 80 | .880 | .92 | 82.0 | 75.6 | 74 | 443.3 | N. | Cloudy. | 9 str. |
| 3.00 | 80 | .860 | .90 | 83.4 | 77.0 | 73 | 443.7 | NE. | Cloudy. | 9 str. |
| 5.00 | 82 | .867 | .90 | 81.0 | 76.2 | 79 | 443.8 | Calm. | Clear. | 2 cir., cir. str., and str. about horizon. |
| 6.00 | 81 | .883 | .92 | 77.5 | 74.8 | 86 | 443.8 | Calm. | Clear. | 1 cir., cir. str., and str. about horizon. |
| 9.00 | 80 | .938 | .98 | 76.0 | 74.3 | 94 | 444.9 | Calm. | Clear. | 0. |

*Miscellaneous.*—Minimum, 72.4. Minimum at ground, 73.0. Maximum, 84.5.

Rained hard and steadily after 1.00 a. m. until 9.50 a. m. Rainfall to 7.00 a. m., 4.2 inches; after 7.00 a. m., 0.5 inch; total, 4.7 inches.

MAY 5, 1883.

| Hour. | Barometer. t. | Barometer. Observed reading. | Barometer. Reduced reading. | Thermometer. Dry. | Thermometer. Wet. | Rel. hum. | Anemometer. | Wind. | Weather. | Clouds. |
|---|---|---|---|---|---|---|---|---|---|---|
| A. M. | | | | | | | | | | |
| 7.00 | 79 | 29.945 | 29.99 | 80.9 | 77.8 | 88 | 463.0 | NE. | Clear. | 2 cum. and str. |
| 8.00 | 81 | .957 | 30.00 | 82.2 | 77.7 | 82 | 469.7 | NE. | Clear. | 1 cum. and str. |
| 8.30 | 82 | .952 | 29.99 | 82.5 | 78.0 | 81 | 472.7 | NE. | Clear. | 2 cum. and str. |
| 9.00 | 82 | .950 | .99 | 83.0 | 77.7 | 80 | 476.4 | NE. | Clear. | 2 cum. and str. |
| 9.30 | 83 | .955 | .99 | 83.0 | 78.2 | 80 | 480.0 | E. | Clear. | 2 cum. |
| 10.00 | 83 | .955 | .99 | 83.2 | 78.1 | 79 | 484.0 | E. | Fair. | 3 cum. |
| 10.30 | 84 | .945 | .97 | 83.3 | 78.0 | 79 | 488.4 | E. | Clear. | 2 cum. |
| 11.00 | 84 | .932 | .96 | 83.7 | 77.8 | 75 | 492.0 | E. | Clear. | 2 cum. |
| 11.30 | 84 | .918 | .95 | 83.7 | 78.5 | 81 | 496.5 | E. | Clear. | 2 cum. |
| 12.00 | 84 | .912 | .94 | 84.0 | 78.5 | 77 | 501.2 | E. | Fair. | 1 cum., cir. str., and str. |
| P. M. | | | | | | | | | | |
| 1.00 | 85 | .877 | .90 | 79.0 | 78.0 | 97 | 507.4 | Calm. | Fair. | 7 cum., nim. in east horizon. |
| 2.00 | 85 | .870 | .89 | 80.0 | 77.5 | 88 | 513.9 | E. | Rain. | 10 cum. and nim. |
| 3.00 | 84 | .852 | .88 | 82.5 | 76.7 | 76 | 519.4 | E. | Fair. | 6 cum. and str. |
| 6.00 | 84 | .876 | .91 | 81.8 | 78.1 | 83 | 532.1 | E. | Fair. | 4 cum. and str. |
| 9.00 | 83 | .910 | .94 | 81.7 | 77.9 | 83 | 550.9 | NE. | Clear. | 1 cum. in horizon. |

*Miscellaneous.*—Minimum, 75.4. Minimum at ground, 74.4. Maximum, 84.3.

Rain, 5.30–6.00 a. m., giving 0.4 inch; 12.45–12.55 p. m., giving 0.15 inch; and 1.50 to 2.10 p. m., inappreciable; total 0.55 inch.

2.45 p. m., top of a rainbow seen in eastern horizon.

5.45 p. m., one heavy dark band extended from clouds in the west to the eastern horizon, evidently the shadow of the clouds.

MAY 6, 1883.

| Hour. | Barometer. t. | Barometer. Observed reading. | Barometer. Reduced reading. | Thermometer. Dry. | Thermometer. Wet. | Rel. hum. | Anemometer. | Wind. | Weather. | Clouds. |
|---|---|---|---|---|---|---|---|---|---|---|
| A. M. | | | | | | | | | | |
| 7.00 | 82 | 29.940 | 29.98 | 81.5 | 78.1 | 86 | 622.2 | E. | Fair. | 3 cum. |
| 8.00 | 83 | .949 | .98 | 83.3 | 79.4 | 81 | 631.3 | E. | Fair. | 2 cum. and haze. |
| 8.30 | 83 | .953 | .99 | 84.9 | 78.9 | 74 | 636.0 | E. | Fair. | 3 cum. and haze. |
| 9.00 | 83 | .953 | .99 | 83.0 | 79.0 | 82 | 640.1 | E. | Fair. | 4 cum. and haze. |
| 9.30 | 83 | .960 | .99 | 79.6 | 78.6 | 98 | 645.3 | E. | Cloudy. | 9 cum. |
| 9.45 | 86 | .958 | .98 | 82.7 | 79.8 | 89 | 647.2 | E. | Fair. | 3 cum. |
| 9.57 | 83 | .952 | .98 | 83.6 | 80.0 | 83 | 649.3 | E. | Fair. | 3 cum. |

For observations in this interval see "Special Observations in connection with the Solar Eclipse."

| Hour. | Barometer. t. | Barometer. Observed reading. | Barometer. Reduced reading. | Thermometer. Dry. | Thermometer. Wet. | Rel. hum. | Anemometer. | Wind. | Weather. | Clouds. |
|---|---|---|---|---|---|---|---|---|---|---|
| P. M. | | | | | | | | | | |
| 1.15 | 87 | 29.843 | 29.86 | 85.0 | 78.9 | 74 | 676.0 | E. | Clear. | 2 cum. |
| 1.30 | 88 | .845 | .86 | 85.0 | 78.6 | 74 | 678.3 | E. | Clear. | 2 cum. |
| 2.00 | 86 | .848 | .87 | 85.0 | 79.0 | 74 | 682.6 | E. | Clear. | 1 cum. |
| 2.30 | 85 | .847 | .87 | 84.4 | 78.7 | 76 | 686.2 | E. | Fair. | 3 cum. |
| 3.00 | 85 | .848 | .87 | 84.2 | 78.8 | 76 | 690.3 | E. | Clear. | 2 cum. |
| 3.30 | 85 | .848 | .87 | 84.2 | 79.9 | 76 | 693.7 | E. | Fair. | 4 cum. |
| 4.00 | 84 | .850 | .88 | 83.8 | 78.3 | 78 | 697.0 | E. | Fair. | 3 cum. |
| 4.30 | 84 | .856 | .89 | 83.1 | 78.4 | 80 | 700.4 | E. | Clear. | 2 cum. |
| 5.00 | 83 | .865 | .90 | 82.8 | 78.0 | 80 | 703.7 | E. | Clear. | 2 cum. |
| 6.00 | 83 | .875 | .91 | 82.1 | 77.9 | 82 | 710.3 | E. | Fair. | 3 cum. and haze. |
| 9.00 | 82 | .922 | .96 | 82.0 | 77.9 | 82 | 738.2 | E. | Clear. | 2 cum. |

*Miscellaneous.*—Minimum, 79.2. Minimum at ground, 78.9. Maximum, 85.5 (modified by the eclipse).
Showers 8.00–9.00 and 9.15–9.25 a. m., giving 0.10 inch.

MAY 7, 1883.

| Hour. | Barometer. t. | Barometer. Observed reading. | Barometer. Reduced reading. | Thermometer. Dry. | Thermometer. Wet. | Rel. hum. | Anemometer. | Wind. | Weather. | Clouds. |
|---|---|---|---|---|---|---|---|---|---|---|
| A. M. | | | | | | | | | | |
| 7.00 | 82 | 29.927 | 29.96 | 79.6 | 76.8 | 89 | 840.7 | E. | Rain. | 10 str. |
| 9.00 | 82 | .955 | .99 | 85.0 | 79.8 | 80 | 828.0 | E. | Fair. | 4 cum. |
| 12.00 | 83 | .888 | .92 | 86.0 | 79.8 | 74 | - - - | E. | Fair. | 4 cum. |
| P. M. | | | | | | | | | | |
| 6.00 | 84 | .813 | .84 | 81.9 | 76.3 | 74 | 914.3 | E. | Fair. | 3 cum. |
| 9.00 | 83 | .887 | .92 | 81.8 | 76.4 | 78 | 941.9 | E. | Clear. | 1 cum. |

*Miscellaneous.*—Minimum, 77.7. Maximum, 87.0.
Rained at intervals in night and between 7.00 and 9.00 a. m., giving 0.25 inch.

MAY 8, 1883.

| Hour. | Barometer. t. | Barometer. Observed reading. | Barometer. Reduced reading. | Thermometer. Dry. | Thermometer. Wet. | Rel. hum. | Anemometer. | Wind. | Weather. | Clouds. |
|---|---|---|---|---|---|---|---|---|---|---|
| A. M. | | | | | | | | | | |
| 7.00 | 81 | 29.870 | 29.91 | 81.7 | 76.8 | 80 | 33.0 | E. | Fair. | 4 cum. |
| 12.00 | 84 | .828 | .86 | 83.6 | 79.0 | 81 | 81.3 | E. | Cloudy. | 9 cum. |
| P. M. | | | | | | | | | | |
| 6.00 | 83 | .800 | .83 | 82.2 | 78.2 | 81 | 143.5 | E. | Fair. | 4 cum. |
| 9.00 | 82 | .860 | .90 | 81.8 | 77.9 | 83 | 170.4 | E. | Clear. | 2 cum. |

*Miscellaneous.*—Minimum, 79.9. Minimum at ground, 80.2. Maximum, 86.4.
Several showers between 7.00 and 12.00 a. m.; inappreciable.

MAY 9, 1883.

| Hour. | Barometer. t. | Barometer. Observed reading. | Barometer. Reduced reading. | Thermometer. Dry. | Thermometer. Wet. | Rel. hum. | Anemometer. | Wind. | Weather. | Clouds. |
|---|---|---|---|---|---|---|---|---|---|---|
| A. M. | | | | | | | | | | |
| 7.00 | 81 | 29.867 | 29.91 | 79.0 | 76.5 | 91 | 240.5 | E. | Cloudy. | 10 str. |

Minimum, 78.0.

*Special observations in connection with Solar Eclipse, May 6, 1883.*

| Hour. | Barometer. t. | Barometer. Observed reading. | Barometer. Reduced reading. | Thermometer. Dry. | Thermometer. Wet. | Rel. hum. | Anemometer. | Wind. | Weather. | Clouds. |
|---|---|---|---|---|---|---|---|---|---|---|
| A. M. | | | | | | | | | | |
| 10.00 | - - | - - - - - | - - - - - | - - - | - - - | - - | 649.4 | E. | - - - | |
| 10.05 | - | - - - - - | - - - - - | - - - | - - - | - - | 650.6 | E. | - - - | |
| 10.10 | - - | - - - - - | - - - - - | - - - | - - - | - - | 651.3 | E. | - - - | |
| 10.15 | 83 | 29.955 | 29.987 | 84.1 | 79.9 | 81 | 651.9 | E. | Clear. | 2 cum. |
| 10.20 | - - | - - - - - | - - - - - | - - - | - - - | - - | 652.7 | E. | - - - | |
| 10.25 | - - | - - - - - | - - - - - | - - - | - - - | - - | 653.2 | E. | - - - | |
| 10.30 | 84 | .942 | .971 | 84.5 | 80.1 | 81 | 654.0 | E. | Clear. | 2 cum. in horizon. |
| 10.35 | - - | - - - - - | - - - - - | - - - | - - - | - - | 654.5 | E. | - - - | |
| 10.40 | 84 | .936 | .965 | 84.0 | 79.9 | 82 | 655.0 | E. | Fair. | 3 cum. |
| 10.45 | - - | - - - - - | - - - - - | - - - | - - - | - - | 656.0 | E. | - - - | |
| 10.50 | - - | - - - - - | - - - - - | - - - | - - - | - - | 656.7 | E. | - - - | |
| 10.55 | - - | - - - - - | - - - - - | - - - | - - - | - - | 657.3 | E. | - - - | |
| 11.00 | 84 | .915 | .914 | 83.5 | 78.4 | 78 | 658.1 | E. | - - - | |
| 11.05 | - - | - - - - - | - - - - - | - - - | - - - | - - | 659.0 | E. | - - - | |
| 11.10 | 85 | .920 | .945 | 83.0 | 78.5 | 80 | 659.6 | E. | Clear. | 2 cum. |
| 11.15 | 85 | .912 | .937 | - - - | - - - | - - | 660.2 | E. | - - - | |
| 11.20 | 85 | .902 | .927 | 82.7 | 78.4 | 83 | 661.0 | E. | Fair. | 3 cum. |
| 11.25 | 86 | .907 | .928 | - - - | - - - | - - | 661.7 | E. | - - - | |

11.32–11.37 a. m. total phase of eclipse.

| Hour. | Barometer. t. | Barometer. Observed reading. | Barometer. Reduced reading. | Thermometer. Dry. | Thermometer. Wet. | Rel. hum. | Anemometer. | Wind. | Weather. | Clouds. |
|---|---|---|---|---|---|---|---|---|---|---|
| 11.40 | - - | - - - - - | - - - - - | - - - | - - - | - - | 663.7 | E. | - - - | |
| 11.43 | 83 | .903 | .935 | 82.0 | 77.5 | 82 | - - | E. | Fair. | 4 cum. |
| 11.45 | - - | - - - - - | - - - - - | - - - | - - - | - - | 661.4 | E. | - - - | |
| 11.50 | 83 | .908 | 910 | 82.2 | 77 7 | 81 | 665.0 | E. | Fair. | 3 cum. |
| 11.55 | - - | - - - - - | - - - - - | - - - | - - - | - - | 665.7 | E. | - - - | |
| 12.00 | 83 | .907 | .939 | 82.2 | 77.8 | 81 | 666.3 | E. | Fair. | 1 cum. |
| P. M. | | | | | | | | | | |
| 12.05 | - - | - - - - - | - - - - - | - - - | - - - | - - | 667.0 | E. | - - - | |
| 12.10 | 83 | .903 | .935 | 83.0 | 78.1 | 79 | 667.5 | E. | Cloudy. | 7 cum. |
| 12.15 | - - | - - - - - | - - - - - | - - - | - - - | - - | 668.3 | E. | - - - | |
| 12.20 | 84 | .887 | .916 | 82.8 | 77.9 | 80 | 669.0 | E. | Fair. | 5 cum. |
| 12.25 | - - | - - - - - | - - - - - | - - - | - - - | - - | 669.9 | E. | - - - | |
| 12.30 | 85 | 29.878 | 29.903 | 83.7 | 78.1 | 78 | 670.3 | E. | Clear. | 2 cum. |
| 12.35 | - - | - - - - - | - - - - - | 84.0 | 78.5 | 77 | 671.0 | E. | Clear. | 2 cum. |
| 12.40 | - - | - - - - - | - - - - - | - - - | - - - | - - | 671.6 | E. | - - - | |
| 12.45 | - - | - - - - - | - - - - - | - - - | - - - | - - | 672.3 | E. | - - - | |
| 12.50 | 86 | 29.868 | 29.889 | 81.4 | 78.9 | 76 | 672.9 | E. | Clear. | 2 cum. |
| 12.55 | - - | - - - - - | - - - - - | - - - | - - - | - - | 673.5 | E. | - - - | |
| 1.00 | 85 | 29.863 | 29.888 | 81.8 | 79.2 | 78 | 674.2 | E. | Clear. | 2 cum. |
| 1.05 | - - | - - - - - | - - - - - | - - - | - - - | - - | 674.7 | E. | - - - | |
| 1.10 | - - | - - - - - | - - - - - | - - - | - - - | - - | 675.3 | E. | - - - | |
| 1.15 | 87 | 29.843 | 29.860 | 85.0 | 78.9 | 74 | 676.0 | E. | Clear. | 2 cum. |

*Miscellaneous.*—Minimum during eclipse, 81.4. Maximum before eclipse, 84.6, at 10.30 a. m., when partial eclipse had been in progress twenty-six minutes. Maximum after eclipse, 85.2, at 1.15 p. m., five minutes before last contact. The temperature remained almost stationary until after 2.00 p. m.

11.10 a. m., color of sky bluish, but greenish about the horizon.

*Condensed meteorological summary.*

| Date. | Temperature. | | | 7 a. m. | | | 12 m. | | | 9 p. m. | | | Rain-fall. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Min. | Max. | Mean. | Red'd bar. | Air temp. | Rel. hum. | Red'd bar. | Air temp. | Rel. hum. | Red'd bar. | Air temp. | Rel. hum. | |
| 1883. | | | | | | | | | | | | | *Inches.* |
| April 25 | 78.2 | 88.2 | 83.2 | 29.95 | 81.9 | 82 | 29.93 | 86.0 | 74 | 29.96 | 82.2 | 82 | *½ |
| 26 | 80.8 | 87.8 | 84.3 | .99 | 82.8 | 80 | .93 | 87.2 | 70 | .98 | 79.2 | 88 | 0.3 |
| 27 | 78.1 | 88.3 | 83.2 | .96 | 82.0 | 80 | .92 | 87.2 | 74 | .90 | 81.6 | 80 | (†) |
| 28 | 79.2 | 89.3 | 84.2 | .93 | 79.9 | 85 | .87 | 87.2 | 72 | .91 | 82.0 | 80 | *0.2 |
| 29 | 77.7 | 88.4 | 83.0 | .91 | 82.2 | 79 | .84 | 87.9 | 70 | .87 | 82.3 | 76 | 0 |
| 30 | 79.5 | 88.2 | 83.8 | .89 | 82.8 | 83 | .84 | 86.8 | 73 | .90 | 82.0 | 82 | (†) |
| May 1 | 80.2 | 87.6 | 83.9 | .92 | 82.8 | 75 | .87 | 86.5 | 67 | .93 | 81.5 | 78 | 0 |
| 2 | 80.2 | 88.7 | 84.4 | .94 | 82.0 | 72 | .87 | 87.8 | 66 | .94 | 81.0 | 74 | 0 |
| 3 | 76.2 | 88.1 | 82.2 | 29.97 | 81.5 | 78 | 29.89 | 86.9 | 66 | .97 | 78.0 | 88 | (‡) |
| 4 | 72.4 | 84.5 | 78.4 | 30.03 | 74.2 | 99 | 30.00 | 81.8 | 75 | .98 | 76.0 | 94 | 4.7 |
| 5 | 75.4 | 84.3 | 79.8 | 29.99 | 80.9 | 88 | 29.94 | 84.0 | 77 | .94 | 81.7 | 83 | 0.6 |
| 6 | 79.2 | *a*85.5 | *a*82.4 | .98 | 81.5 | 86 | .94 | *a*82.2 | 81 | .96 | 82.0 | 82 | 0.1 |
| 7 | 77.7 | 87.0 | 82.4 | .96 | 79.6 | 89 | .92 | 86.0 | 74 | .92 | 81.8 | 78 | 0.3 |
| 8 | 79.9 | 86.4 | 83.2 | .91 | 81.7 | 80 | .86 | 83.6 | 81 | .90 | 81.8 | 83 | (†) |
| 9 | 78.0 | - - | - - | .91 | 79.0 | 91 | - - | - - | - - | - - | - - | - - | - - |
| | | | | | | | | | | | | | ‖⅘ |
| Total rainfall | | | | | | | | | | | | | 7.5 |

*a* Eclipse caused lower reading than it would have reached.

* Estimated. † Inappreciable. ‡ Entered under 4th. ‖ Estimated on April 23.

*Wind velocities.*

HOURLY MOVEMENTS IN MILES.

| Hour. | April 26. | April 27. | April 28. | April 29. | April 30. | May 1. | May 2. | May 3. | May 4. | May 5. |
|---|---|---|---|---|---|---|---|---|---|---|
| A. M. | | | | | | | | | | |
| 6.00 to 7.00 | - - | 8.4 | 5.0 | - - | 3.9 | - - | - - | - - | - - | - - |
| 7.00 to 8.00 | 7.1 | 10.1 | 4.5 | 6.4 | 4.2 | 7.7 | 7.8 | 2.8 | 5.4 | 6.7 |
| 8.00 to 9.00 | 8.4 | 7.6 | 7.2 | 5.7 | 5.9 | 7.1 | 7.1 | 3.7 | 5.3 | 6.7 |
| 9.00 to 10.00 | 5.2 | 9.7 | 7.1 | 5.6 | 4.2 | 8.0 | 5.5 | 5.7 | 9.1 | 7.6 |
| 10.00 to 11.00 | 7.7 | 7.6 | 4.0 | 5.7 | 4.4 | 8.5 | 2.9 | 6.0 | 5.6 | 8.0 |
| 11.00 to 12.00 | 6.9 | 6.4 | 3.6 | 5.9 | 3.9 | 7.7 | 3.0 | 6.5 | 6.4 | 9.2 |
| P. M. | | | | | | | | | | |
| 12.00 to 1.00 | 7.6 | 6.9 | 2.9 | 5.7 | 10.6 | 6.4 | 2.3 | 4.5 | 7.0 | 6.2 |
| 1.00 to 2.00 | 7.6 | 6.3 | 2.8 | 5.0 | 9.8 | 7.1 | 0.8 | 4.0 | 0.7 | 6.5 |
| 2.00 to 3.00 | 6.9 | 5.7 | 5.7 | 3.6 | 9.9 | 6.7 | 0.8 | - - | 0.4 | 5.5 |
| 3.00 to 4.00 | 4.3 | 5.2 | 5.5 | - | 6.6 | - - | 1.6 | - - | 0.1 | - - |
| 4.00 to 5.00 | 2.7 | 5.1 | 6.2 | - - | 5.3 | - - | 2.6 | - - | 0.0 | - - |
| 5.00 to 6.00 | 5.9 | 4.6 | 5.8 | - - | 6.6 | - - | - - | - - | 0.0 | - - |

Observations made on May 6 are given in connection with the report upon the eclipse observations.

TOTAL MOVEMENTS AND HOURLY AVERAGES.

| Date. | 7 a. m. to 9 p. m. | | 9 p. m. to 7 a. m. following day. | | 7 a. m. to 7 a. m. following day. | |
|---|---|---|---|---|---|---|
| | Total movement. | Hourly average. | Total movement. | Hourly average. | Total movement. | Hourly average. |
| April 26 | 86.2 | 6.16 | 66.3 | 6.63 | 152.5 | 6.35 |
| 27 | 90.9 | 6.49 | 56.8 | 5.68 | 147.7 | 6.15 |
| 28 | 76.8 | 5.49 | 62.0 | 6.20 | 138.8 | 5.78 |
| 29 | 84.8 | 6.06 | 69.6 | 6.96 | 154.4 | 6.43 |
| 30 | 85.5 | 6.11 | 69.4 | 6.94 | 154.9 | 6.45 |
| May 1 | 96.8 | 6.91 | 63.3 | 6.33 | 160.1 | 6.67 |
| 2 | 42.4 | 3.03 | 18.3 | 1.83 | 60.7 | 2.53 |
| 3 | 75.8 | 5.41 | 17.0 | 1.70 | 92.8 | 3.87 |
| 4 | 41.1 | 2.94 | 18.1 | 1.81 | 59.2 | 2.47 |
| 5 | 87.9 | 6.28 | 71.3 | 7.13 | 159.2 | 6.63 |
| 6 | 116.0 | 8.29 | 72.5 | 7.25 | 188.5 | 7.85 |
| 7 | 131.2 | 9.37 | 81.1 | 8.11 | 212.3 | 8.85 |
| 8 | 137.4 | 9.81 | 70.1 | 7.01 | 207.5 | 8.65 |
| Average | | | | | | 6.05 |

OBSERVATIONS OF THE RAIN-BAND.

The instrument used in these observations was a BROWNING rain-band spectroscope. Two pointings were made at each observation, the first towards the horizon, the second to an altitude of about 45°, and the intensity of the band estimated on a scale of 5.

| Date. | | Hour. | Alt. 0° | Alt. 45° | Sum. | Remarks. |
|---|---|---|---|---|---|---|
| | | A. M. | | | | |
| April | 27 | 8.00 | 4 | 3 | 7 | Rain-lines very distinct. |
| | 28 | 7.00 | 4 | 3 | 7 | On rain clouds in north; rain-lines distinct. |
| | 28 | 7.00 | 5 | 4 | 9 | On clear sky in south; rain-lines indistinct. |
| | 29 | 8.30 | 3 | 2 | 5 | |
| May | 1 | 6.45 | 4 | 3 | 7 | Rain-lines distinct. |
| | 1 | 7.30 | 4 | 3 | 7 | Do. |
| | 1 | 10.00 | 4 | 3 | 7 | Do. |
| | 2 | 8.00 | 4 | 3 | 7 | Do. |
| | 2 | 11.30 | 4 | 3 | 7 | Do. |
| | 3 | 7.00 | 4 | 3 | 7 | Do. |
| | 3 | 9.00 | 3 | 2 | 5 | Rain-lines indistinct. |
| | 4 | 8.00 | 4 | 4 | 8 | On clouds; lines indistinct. |
| | 5 | 9.00 | 5 | 3 | 8 | |
| | 6 | 10.30 | 4 | 3 | 7 | Lines indistinct. |
| | 6 | 11.10 | 3 | 2 | 5 | Do. |

*METEOROLOGICAL OBSERVATIONS DURING THE ECLIPSE.*

The meteorological observations made during the stay at Caroline Island have been discussed in what precedes. It remains to speak of the special observations made at the time of the eclipse, and to show what conclusions may be derived from them. Observations of the barometer, dry and wet bulb thermometers, maximum and minimum thermometers were made by myself as opportunity offered during the progress of the eclipse. Observations of the conjugate thermometers, VIOLLE's conjugate bulbs, black and white bulbs in the sun, and of the direction and velocity of the wind, were made by Seaman J. C. HAROLD every five minutes between 10.00 a. m. and 1.15 p. m.

## GENERAL WEATHER CONDITIONS.

The sky during the early portion of the 6th of May was partly cloudy, and the clouds threatened rain. Slight showers occurred between 8.00 and 9.00 a. m., and a heavy shower at 9.15 a. m., after which the sky cleared. But at no time during the day was the atmosphere free from a haze, which was apparent to the eye and also showed itself in the readings of the instruments. The relative humidity was above the average, being 81 per cent. at noon and 71 per cent. at 2.00 p. m., and the radiation instruments gave lower readings than on other days, especially in the morning. Passing clouds prevailed during the day, but interfered only a little with the observations of the eclipse. At the first and fourth contacts there were no clouds in the vicinity of the sun. Immediately after the second contact a light cloud passed over the eclipsed sun, and remained for a portion of the first minute of totality. There were no clouds during the remainder of the total phase, but immediately after third contact a cloud again covered the sun for forty seconds. Another cloud, heavier than its predecessors, obscured the sun for several minutes, beginning with the fifth minute after third contact. It will be seen from the above that the observers were especially fortunate in the weather at the time of totality, but it should be remembered that at all times the atmosphere was hazy. The wind blew steadily during the day, averaging 8.3 miles an hour, as recorded by the anemometer 9 feet 7 inches above the ground.

## BAROMETRIC PRESSURE.

The barometric observations show a slight, but well marked, rise in pressure during the eclipse. In order to determine whether this phenomenon has any real relation to the eclipse it is necessary to inquire whether a similar result might not have occurred on other days, and, also, what was the usual course of pressure between 10.00 a. m. and 1.00 p. m. The regularity of movement in the pressure from day to day renders such an inquiry possible, even though the observations extend over a short period.

On six days preceding the eclipse half-hourly observations of pressure were made between 10.00 a. m. and 1.00 p. m. These reduced are as follows:

| | 10.00. | 10.30. | 11.00. | 11.30. | 12.00. | 12.30. | 1.00. |
|---|---|---|---|---|---|---|---|
| April 28 | 29.934 | 29.919 | 29.906 | 29.891 | 29.868 | 29.861 | 29.849 |
| 29 | .904 | .894 | .862 | .840 | .836 | 812 | †.747 |
| 30 | .893 | .889 | .869 | .853 | .844 | - - - | .826 |
| May 2 | .942 | .929 | .916 | .895 | .875 | .853 | .846 |
| 3 | .967 | .952 | .933 | .902 | .887 | .861 | .846 |
| 5 | .987 | .974 | .961 | .947 | .941 | - - - | .902 |
| Mean - - | 29.938 | 29.926 | 29.908 | 29.888 | 29.875 | *29.855 | 29.844 |

* Missing values interpolated. † This reading probably should be 29.797.

Fig. 16.

BAROMETRIC CURVE DURING ECLIPSE.

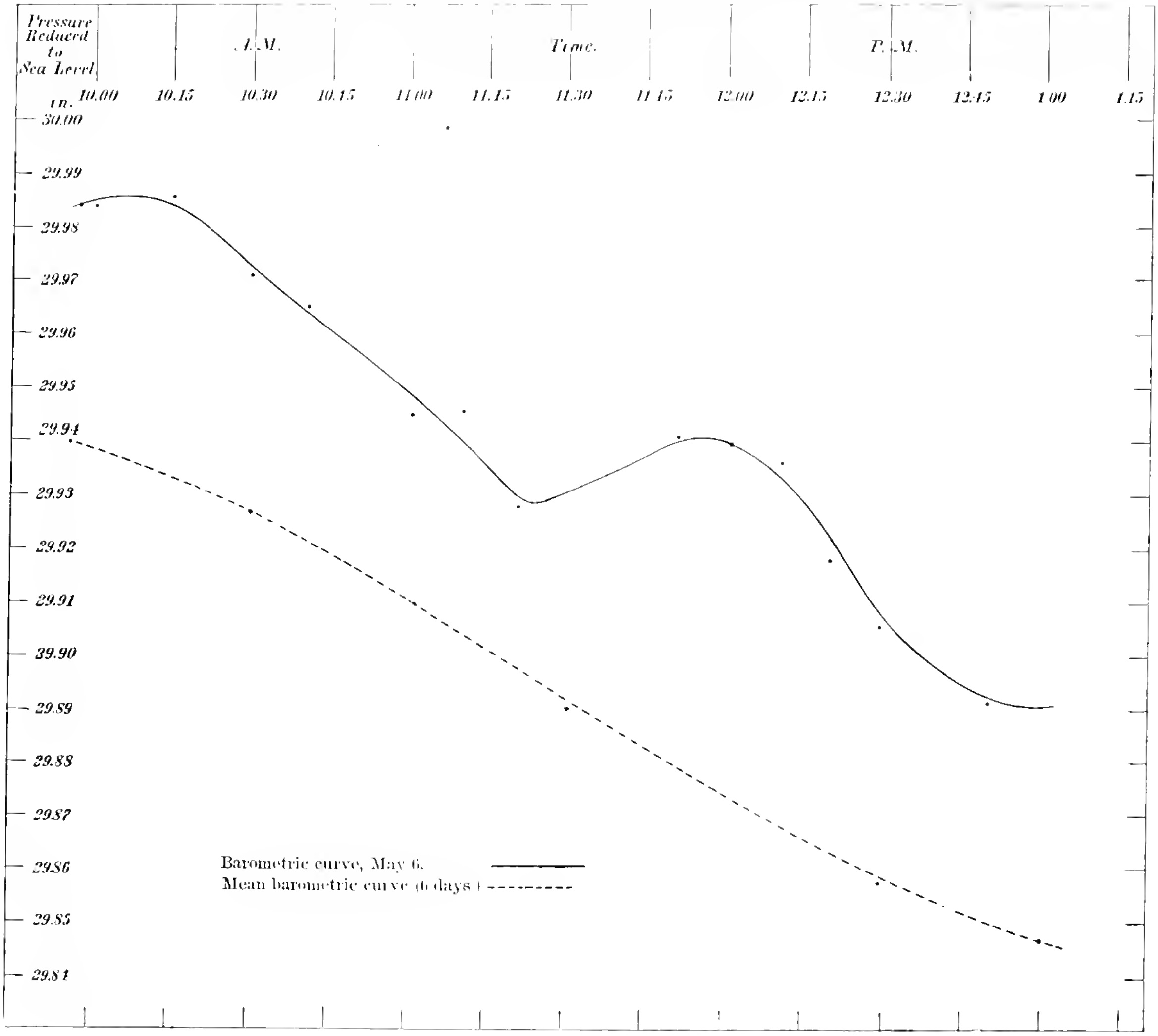
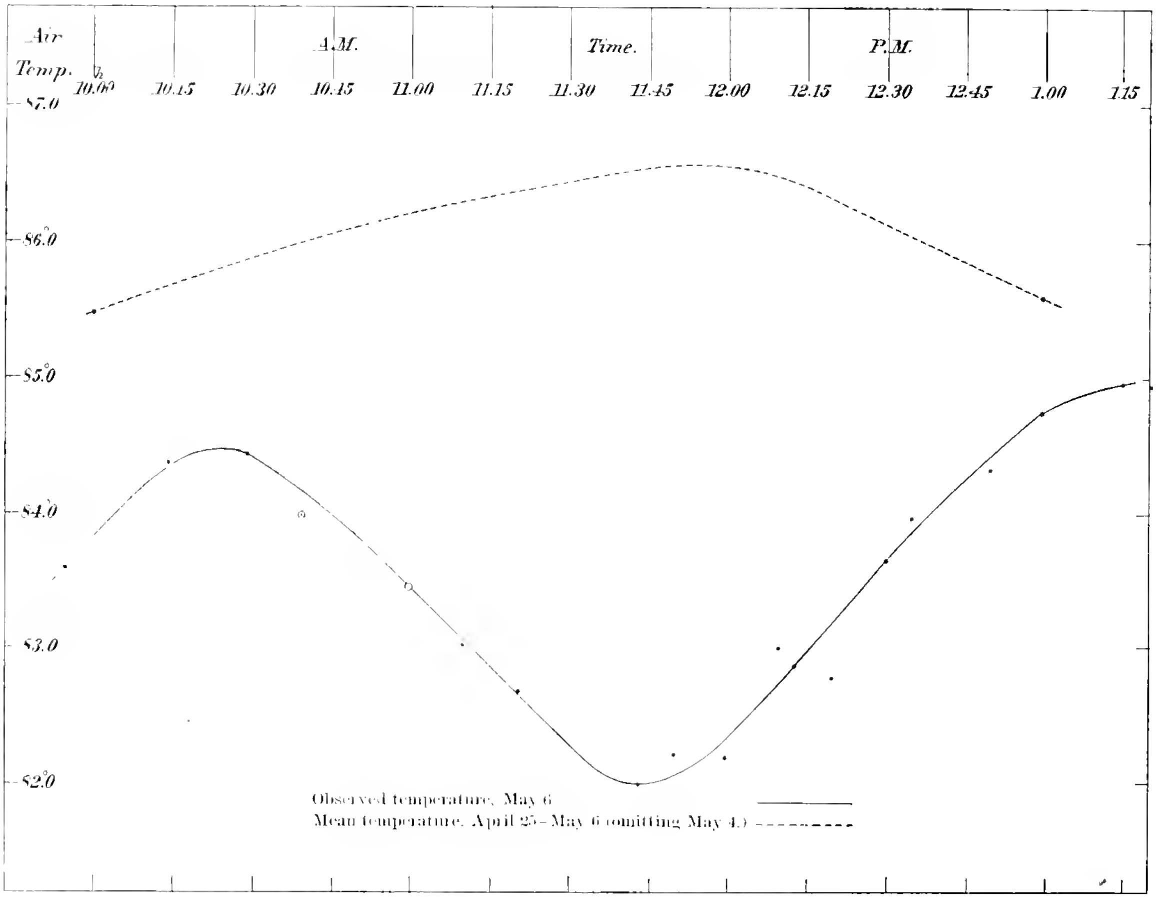


Fig. 17.

TEMPERATURE CURVE DURING ECLIPSE.



The following table contains the reduced readings for May 6, and a comparison with values interpolated from the mean values above given.

BAROMETRIC PRESSURE

| Hour. | May 6. | Mean of six days. | Diff. | Diff. minus mean diff. |
|---|---|---|---|---|
| A. M. | | | | |
| 9.57 | 29.985 | 29.938 | 0.047 | — 0.001 |
| 10.15 | .987 | .932 | .055 | + .007 |
| 10.30 | .971 | .926 | .045 | — .003 |
| 10.40 | .965 | .920 | .045 | — .003 |
| 11.00 | .944 | .908 | .036 | — .012 |
| 11.10 | .945 | .901 | .044 | — .004 |
| 11.15 | .937 | .898 | .039 | — .009 |
| 11.20 | .927 | .895 | .032 | — .016 |
| 11.25 | .928 | .891 | .037 | — .011 |
| 11.43 | .935 | .882 | .053 | + .005 |
| 11.50 | .940 | .879 | .061 | + .013 |
| 12.00 | .939 | .875 | .064 | + .016 |
| P. M. | | | | |
| 12.10 | .935 | .868 | .067 | + .019 |
| 12.20 | .916 | .862 | .054 | + .006 |
| 12.30 | .903 | .855 | .048 | .000 |
| 12.50 | .889 | .848 | .041 | — .007 |
| 1.00 | .888 | .844 | 0.044 | — .004 |
| Mean diff. - - - - - | | | 0.048 | |

The above tables show that on all days but May 6 there was a steady fall in pressure, and therefore the observed rise on that day was peculiar to the day. The last column of the second table indicates a more rapid fall than the average during the first partial phase, and also that the time of the maximum difference from the average course occurred at about 12.10 p. m., or thirty-three minutes after the close of the total phase. The highest reading was recorded at 11.50 a. m., or thirteen minutes after the end of totality.

While the rise in pressure was small, being at its maximum only 0.019 above the average value, it is yet greater than the errors of observation. The instrument used can be read accurately within 0.005, and as it was kept at nearly uniform temperature during the period of observation, the possible uncertainty from failure of the attached thermometer to record the temperature of the instrument can scarcely amount to 0.005. On the supposition that the errors have the same sign, there still remains 0.01 inch which is not accounted for, and the observed progression depends upon six or more observations. It is not difficult to imagine also that the inflow of air towards the path of the shadow might be sufficient to cause an increased pressure susceptible of measurement by a sensitive barometer.

TEMPERATURE.

The effect of the eclipse in reducing the temperature of the air may be shown by comparing the thermometric readings with those of other days. The mean values of the observed temperature, April 25 through May 5, omitting the rainy day, May 4, are as follows:

| Hour. | Degrees. | Hour. | Degrees. |
|---|---|---|---|
| A. M. | | A. M. | |
| 7.00 | 81.9 | 11.00 | 86.3 |
| 8.00 | 83.4 | 12.00 | 86.7 |
| | | P. M. | |
| 9.00 | 84.9 | 1.00 | 85.7 |
| 10.00 | 85.5 | 2.00 | 85.9 |

The following table contains a comparison between the observed readings on May 6 and values interpolated from the above averages. It will be seen from the column of differences that at 9.57 a. m., before the beginning of the eclipse, the observed reading was 1°.9 below the average, and that at 1.30 p. m., after its close, it was 0.8 below. Interpolating from these values the differences which would probably have existed at the time of the eclipse had there been no unusual phenomenon, we have the values of the effect of the eclipse given in the last column under the heading "Depression."

AIR TEMPERATURE.

| Hour. | May 6. | Average. | Diff. | Regular decrease for the day. | Depression. | |
|---|---|---|---|---|---|---|
| A. M. | | | | | | |
| 9.57 | 83.6 | 85.5 | 1.9 | 1.9 | 0.0 | |
| 10.15 | 84.4 | 85.7 | 1.3 | 1.8 | −0.5 | |
| 10.30 | 84.5 | 85.9 | 1.4 | 1.7 | −0.3 | Maximum, 84°.6. |
| 10.40 | 84.0 | 86.0 | 2.0 | 1.6 | 0.4 | |
| 11.00 | 83.5 | 86.3 | 2.8 | 1.5 | 1.3 | |
| 11.10 | 83.0 | 86.1 | 3.4 | 1.5 | 1.9 | |
| 11.20 | 82.7 | 86.4 | 3.7 | 1.4 | 2.3 | |
| 11.43 | 82.0 | 86.6 | 4.6 | 1.3 | 3.3 | Minimum, 81°.4; maximum depression, 3°.9. |
| 11.50 | 82.2 | 86.6 | 4.4 | 1.3 | 3.1 | |
| 12.00 | 82.2 | 86.7 | 4.5 | 1.2 | 3.3 | |
| P. M. | | | | | | |
| 12.10 | 83.0 | 86.5 | 3.5 | 1.2 | 2.3 | |
| 12.20 | 82.8 | 86.4 | 3.6 | 1.1 | 2.5 | |
| 12.30 | 83.7 | 86.2 | 2.5 | 1.1 | 1.4 | |
| 12.35 | 84.0 | 86.1 | 2.1 | 1.1 | 1.0 | |
| 12.50 | 84.4 | 85.9 | 1.5 | 1.0 | 0.5 | |
| 1.00 | 84.8 | 85.7 | 0.9 | 0.9 | 0.0 | |
| 1.15 | 85.0 | 85.8 | 0.8 | 0.8 | 0.0 | Maximum, 85°.2. |
| 1.30 | 85.0 | 85.8 | 0.8 | 0.8 | 0.0 | |

The maximum depression of temperature was therefore only about 4°, but this was sufficient to reduce the temperature to a value 0°.1 lower than it had been at 7.00 a. m. on the same day, and 0°.6 lower than it was at 9.00 p. m.

HUMIDITY.

The effect of the eclipse upon the humidity may be found by comparing the psychrometric readings taken during the progress of the eclipse with those of other days. The following table gives the result of this comparison, the values in the column headed "average" being deduced from the mean values from April 25 through May 5, omitting May 4. The "regular decrease for the day" is interpolated from the observed differences at 9.57 a. m. and 2.00 p. m.:

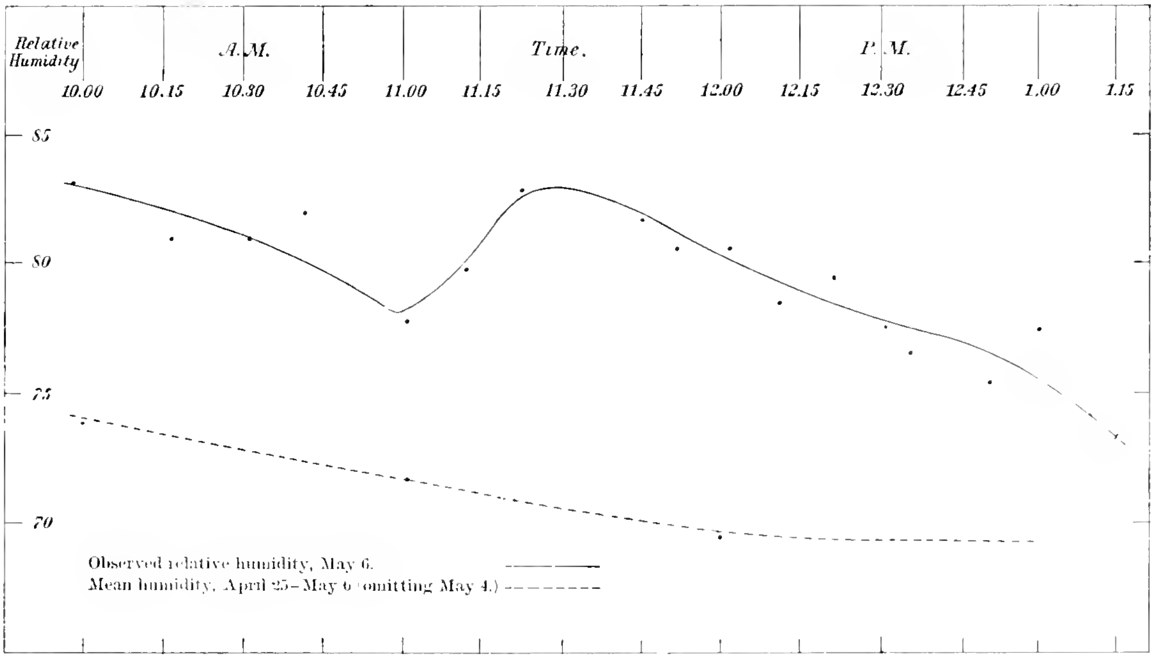
RELATIVE HUMIDITY.

| Hour. | May 6. | Average. | Diff. | Regular decrease for the day. | Diff. |
|---|---|---|---|---|---|
| A. M. | | | | | |
| 9.57 | 83 | 74 | 9 | 9 | 0 |
| 10.15 | 81 | 74 | 7 | 8 | −1 |
| 10.30 | 81 | 73 | 8 | 8 | 0 |
| 10.40 | 82 | 73 | 9 | 7 | 2 |
| 11.00 | 78 | 72 | 6 | 7 | −1 |
| 11.10 | 80 | 72 | 8 | 7 | 1 |
| 11.20 | 83 | 71 | 12 | 7 | 5 |
| 11.43 | 82 | 71 | 11 | 6 | 5 |
| 11.50 | 81 | 70 | 11 | 6 | 5 |
| 12.00 | 81 | 70 | 11 | 6 | 5 |
| P. M. | | | | | |
| 12.10 | 79 | 70 | 9 | 6 | 3 |
| 12.20 | 80 | 70 | 10 | 6 | 4 |
| 12.30 | 78 | 70 | 8 | 6 | 2 |
| 12.35 | 77 | 70 | 7 | 5 | 2 |
| 12.50 | 76 | 70 | 6 | 5 | 1 |
| 1.00 | 78 | 70 | 8 | 5 | 3 |
| 1.15 | 74 | 70 | 4 | 5 | −1 |
| 1.30 | 74 | 71 | 3 | 4 | −1 |
| 2.00 | 74 | 71 | 3 | 3 | 0 |

The above table indicates an increase in the relative humidity during the eclipse, reaching *five* per cent.

**Fig. 18.**

CURVE OF RELATIVE HUMIDITY DURING ECLIPSE.



## WIND.

The present eclipse furnished an unusually favorable opportunity for determining any fluctuations that might occur in the direction and velocity of the wind caused by the eclipse. The regularity of the wind from day to day, both in direction and velocity, made it possible to obtain a reliable basis of comparison. Observations were made every five minutes from 10.00 a. m. to 1.15 p. m., with the result that no appreciable change was detected either in direction or force. The wind blew with almost the same velocity from the eastward during the period of time occupied by the eclipse. The following table gives the observed velocity in miles for every ten minutes from 10.00 a. m. to 1.30 p. m.:

| Time. | Velocity. | Time. | Velocity. | Time. | Velocity. |
|---|---|---|---|---|---|
| 10. 00 to 10. 10 | 1. 9 | 11. 20 to 11. 30 | 1. 4 | 12. 40 to 12. 50 | 1. 3 |
| 10. 10 to 10. 20 | 1. 4 | 11. 30 to 11. 40 | 1. 3 | 12. 50 to 1. 00 | 1. 3 |
| 10. 20 to 10. 30 | 1. 3 | 11. 40 to 11. 50 | 1. 3 | 1. 00 to 1. 10 | 1. 1 |
| 10. 30 to 10. 40 | 1. 0 | 11. 50 to 12. 00 | 1. 3 | 1. 10 to 1. 20 | 1. 5 |
| 10. 40 to 10. 50 | 1. 7 | 12. 00 to 12. 10 | 1. 2 | 1. 20 to 1. 30 | 1. 5 |
| 10. 50 to 11. 00 | 1. 4 | 12. 10 to 12. 20 | 1. 5 | | |
| 11. 00 to 11. 10 | 1. 5 | 12. 20 to 12. 30 | 1. 3 | Mean - - | 1. 38 |
| 11. 10 to 11. 20 | 1. 4 | 12. 30 to 12. 40 | 1. 3 | | |

The mean ten-minute velocity from 7.00 a. m to 9.00 p. m. is exactly the same, viz, 1.38 miles. The observations on other days show the following relation between the velocities from 10.00 a. m. to 2.00 p. m., and those from 7.00 a. m. to 9.00 p. m.:

*Mean wind velocity for each ten minutes.*

| Date. | 10 a. m. to 2 p. m. | 7 a. m. to 9 p. m. | Difference. |
|---|---|---|---|
| April 26 | 1. 24 | 1. 03 | + 0. 21 |
| 27 | 1. 13 | 1. 08 | + .05 |
| 28 | 0. 55 | 0. 98 | — .43 |
| 29 | 0. 93 | 1. 01 | — .08 |
| 30 | 1. 20 | 1. 02 | + .18 |
| May 1 | 1. 24 | 1. 15 | + .09 |
| 2 | 0. 38 | 0. 50 | — .12 |
| 3 | 0. 88 | 0. 90 | — .02 |
| 4 | 0. 82 | 0. 49 | + .33 |
| 5 | 1. 25 | 1. 05 | + .20 |
| Mean - - - - - - - - - | | | + 0. 04 |

Mean of April 26, 27, 29, 30, May 1, 5, when the hourly velocity was greater than 6 miles is +0.11.

Judging from these comparisons it might have been expected that the wind would blow somewhat stronger between the hours of 10.00 a. m. and 2.00 p. m. than during the rest of the day. On the contrary, the observed velocity was the same. Consequently, if the passage of the moon's shadow had any effect at all on the velocity of the wind, it was to slightly diminish it.

## DIURNAL VARIATION IN THE VELOCITY OF THE SOUTHEAST TRADE-WIND.

The series of observations with the anemometer on Caroline Island is not sufficiently extensive to indicate any diurnal periodicity in the wind velocity. During the voyage from Callao, however, the *Hartford* sailed day after day in the region of the southeast trades upon almost the same parallel of latitude, and with but few changes in the positions of the sails, no steam being used. The conditions were so constant during the interval of twenty-two days from March 23 to April 13, in which the vessel sailed in latitude $-11^\circ.5$ from longitude $79^\circ$ to $137^\circ$, that it was thought a tabulation of the hourly speed of the vessel might give some indication of the diurnal course of the wind velocity. The following table was therefore made, which gives the hourly speed, taken from the ship's log, through the courtesy of Captain Carpenter. It will be seen that the mean values show a distinct increase in the evening and a corresponding decrease in the morning, with the maximum at 11.00 p. m. and the minimum at 11.00 a. m. It seems fair to attribute this to the diurnal variation in the wind velocity. There is quite an unexpected regularity in the progression when we consider the approximate nature of the method. If not attributable to diurnal change in the wind itself, it yet indicates a diurnal change in the effect of the wind upon the sails, and is therefore of interest.

*Hourly speed of the U. S. S. Hartford, March 23–April 13.*

| Date. | 1 a. m. | 2 a. m. | 3 a. m. | 4 a. m. | 5 a. m. | 6 a. m. | 7 a. m. | 8 a. m. | 9 a. m. | 10 a. m. | 11 a. m. | 12 m. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *m.* | *m.* | *m.* | *m.* | *m.* | *m.* | *m.* | *m.* | *m.* | *m.* | *m.* | *m.* |
| March 23 | 3.3 | 3.0 | 3.4 | 4.4 | 5.4 | 5.8 | 5.0 | 4.4 | 4.4 | 4.0 | 4.6 | 5.0 |
| 24 | 6.5 | 6.0 | 6.0 | 5.6 | 4.7 | 4.1 | 3.8 | 3.8 | 4.4 | 5.0 | 5.0 | 4.2 |
| 25 | 5.0 | 5.0 | 5.8 | 6.2 | 5.5 | 5.8 | 6.2 | 6.5 | 6.5 | 5.9 | 6.6 | 6.0 |
| 26 | 7.2 | 7.0 | 8.0 | 8.0 | 8.0 | 7.0 | 6.8 | 6.4 | 6.5 | 5.5 | 7.6 | 7.8 |
| 27 | 7.5 | 7.5 | 8.2 | 7.8 | 7.2 | 6.8 | 6.4 | 6.0 | 5.8 | 6.0 | 4.5 | 4.0 |
| 28 | 5.6 | 5.6 | 5.6 | 5.6 | 6.0 | 6.0 | 5.8 | 6.2 | 6.0 | 6.0 | 5.9 | 5.8 |
| 29 | 7.0 | 7.6 | 7.0 | 7.0 | 7.0 | 7.0 | 7.0 | 6.8 | 7.2 | 7.8 | 8.5 | 9.0 |
| 30 | 8.0 | 8.0 | 8.0 | 8.0 | 7.5 | 7.6 | 8.0 | 7.6 | 7.3 | 7.6 | 7.7 | 8.0 |
| 31 | 8.0 | 8.0 | 7.8 | 8.0 | 8.0 | 8.0 | 8.0 | 7.8 | 7.8 | 8.0 | 7.5 | 8.0 |
| April 1 | 8.0 | 7.4 | 6.8 | 6.0 | 7.2 | 7.6 | 7.2 | 6.4 | 7.0 | 7.3 | 6.6 | 5.9 |
| 2 | 8.4 | 8.2 | 7.6 | 7.8 | 7.4 | 7.0 | 7.0 | 6.6 | 6.4 | 6.8 | 7.1 | 6.8 |
| 3 | 6.0 | 6.4 | 5.4 | 5.4 | 5.5 | 5.6 | 6.2 | 6.2 | 5.6 | 5.5 | 5.9 | 6.0 |
| 4 | 7.4 | 7.0 | 7.2 | 7.2 | 7.8 | 7.2 | 6.8 | 6.6 | 6.5 | 5.8 | 6.0 | 6.2 |
| 5 | 7.2 | 6.8 | 7.0 | 8.0 | 7.0 | 5.6 | 6.5 | 6.6 | 6.2 | 5.6 | 5.6 | 6.6 |
| 6 | 7.1 | 6.8 | 5.4 | 5.6 | 5.6 | 5.0 | 4.6 | 5.0 | 5.0 | 4.8 | 4.8 | 4.6 |
| 7 | 7.2 | 7.4 | 7.0 | 7.0 | 6.5 | 6.0 | 6.1 | 5.6 | 6.5 | 6.4 | 6.5 | 6.2 |
| 8 | 6.8 | 7.0 | 6.8 | 7.0 | 7.4 | 7.2 | 6.5 | 6.0 | 6.0 | 6.0 | 5.6 | 6.2 |
| 9 | 5.8 | 5.4 | 5.2 | 4.6 | 4.8 | 4.4 | 4.4 | 4.8 | 5.0 | 4.8 | 4.7 | 5.2 |
| 10 | 4.5 | 4.5 | 4.4 | 4.4 | 4.8 | 4.0 | 2.2 | 2.8 | 2.7 | 3.3 | 4.0 | 3.9 |
| 11 | 6.2 | 6.5 | 6.8 | 6.8 | 6.8 | 6.9 | 7.2 | 7.1 | 6.8 | 6.4 | 6.4 | 6.2 |
| 12 | 6.4 | 6.2 | 6.0 | 6.0 | 6.6 | 7.0 | 6.8 | 6.4 | 6.6 | 6.3 | 6.2 | 6.4 |
| 13 | 6.8 | 6.2 | 6.4 | 5.4 | 4.9 | 5.0 | 5.6 | 6.0 | 5.8 | 5.4 | 5.2 | 5.6 |
| Sums - | 145.9 | 143.5 | 141.8 | 141.8 | 141.6 | 136.6 | 134.1 | 131.6 | 132.0 | 130.2 | 132.5 | 133.6 |
| Means - | 6.6 | 6.5 | 6.4 | 6.4 | 6.4 | 6.2 | 6.1 | 6.0 | 6.0 | 5.9 | 6.0 | 6.1 |

| Date. | 1 p. m. | 2 p. m. | 3 p. m. | 4 p. m. | 5 p. m. | 6 p. m. | 7 p. m. | 8 p. m. | 9 p. m. | 10 p. m. | 11 p. m. | 12 p. m. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *m.* | *m.* | *m.* | *m.* | *m.* | *m.* | *m.* | *m.* | *m.* | *m.* | *m.* | *m.* |
| March 23 | 6.0 | 6.6 | 7.0 | 6.9 | 7.0 | 6.8 | 7.0 | 7.2 | 6.8 | 6.4 | 6.4 | 6.8 |
| 24 | 5.0 | 5.4 | 4.3 | 4.3 | 4.0 | 4.4 | 4.6 | 4.4 | 4.4 | 4.4 | 5.0 | 5.0 |
| 25 | 5.8 | 6.0 | 6.0 | 6.0 | 6.4 | 6.6 | 7.0 | 7.0 | 7.2 | 8.0 | 7.0 | 7.0 |
| 26 | 7.0 | 8.0 | 8.0 | 7.2 | 7.2 | 7.2 | 8.0 | 8.2 | 8.2 | 7.6 | 7.2 | 6.8 |
| 27 | 4.3 | 4.4 | 4.5 | 5.2 | 5.6 | 6.1 | 6.3 | 5.8 | 5.0 | 5.4 | 5.4 | 5.4 |
| 28 | 6.0 | 6.2 | 5.8 | 6.4 | 7.0 | 6.4 | 6.4 | 6.2 | 8.0 | 8.0 | 7.4 | 7.0 |
| 29 | 8.8 | 8.6 | 8.3 | 8.3 | 8.5 | 8.0 | 9.2 | 9.3 | 9.2 | 8.8 | 8.4 | 8.0 |
| 30 | 8.0 | 8.0 | 8.0 | 8.0 | 8.5 | 8.8 | 8.8 | 8.4 | 8.0 | 8.8 | 8.6 | 8.8 |
| 31 | 7.4 | 6.8 | 6.6 | 6.0 | 6.0 | 6.8 | 7.0 | 7.6 | 8.2 | 8.4 | 8.4 | 8.4 |
| April 1 | 6.8 | 7.6 | 7.8 | 7.9 | 7.9 | 7.8 | 7.7 | 7.2 | 7.8 | 8.0 | 8.6 | 8.6 |
| 2 | 6.8 | 6.9 | 6.7 | 6.6 | 7.0 | 7.0 | 7.0 | 7.3 | 7.2 | 6.8 | 7.2 | 6.4 |
| 3 | 6.0 | 6.2 | 6.0 | 6.0 | 6.3 | 6.6 | 6.4 | 7.2 | 7.2 | 7.0 | 7.6 | 7.7 |
| 4 | 5.8 | 5.6 | 5.8 | 5.3 | 6.0 | 6.5 | 7.2 | 7.6 | 7.4 | 7.5 | 7.4 | 7.5 |
| 5 | 5.7 | 6.1 | 6.2 | 6.2 | 6.6 | 6.8 | 7.0 | 6.8 | 7.2 | 7.5 | 7.4 | 7.2 |
| 6 | 4.8 | 5.4 | 5.7 | 6.1 | 6.1 | 5.8 | 6.0 | 6.2 | 6.6 | 6.8 | 7.2 | 7.0 |
| 7 | 6.4 | 6.1 | 6.0 | 6.0 | 6.0 | 6.2 | 6.4 | 6.8 | 7.0 | 7.0 | 7.2 | 6.8 |
| 8 | 6.6 | 5.5 | 5.6 | 5.8 | 6.0 | 5.6 | 5.2 | 6.2 | 6.3 | 5.9 | 6.0 | 6.0 |
| 9 | 4.7 | 4.2 | 3.9 | 4.0 | 3.8 | 3.7 | 3.4 | 3.4 | 3.6 | 3.8 | 4.0 | 4.0 |
| 10 | 4.0 | 4.0 | 4.4 | 5.0 | 5.2 | 4.9 | 4.6 | 4.6 | 5.6 | 5.2 | 6.0 | 6.0 |
| 11 | 6.0 | 6.4 | 6.0 | 6.0 | 5.8 | 6.6 | 7.0 | 7.0 | 7.2 | 7.0 | 6.2 | 6.4 |
| 12 | 6.1 | 5.5 | 4.9 | 5.2 | 5.3 | 5.4 | 5.6 | 5.7 | 6.2 | 7.0 | 7.0 | 7.0 |
| 13 | 5.4 | 5.4 | 5.0 | 5.0 | 5.0 | 5.0 | 4.5 | 4.2 | 4.0 | 4.4 | 4.8 | 4.4 |
| Sums - | 133.4 | 134.9 | 132.5 | 133.4 | 137.2 | 139.0 | 142.3 | 144.3 | 148.3 | 149.7 | 150.4 | 148.2 |
| Means - | 6.1 | 6.1 | 6.0 | 6.1 | 6.2 | 6.3 | 6.5 | 6.6 | 6.7 | 6.8 | 6.8 | 6.7 |

## OBSERVATIONS OF SOLAR RADIATION.

In addition to the ordinary meteorological observations, a series of observations of solar radiation was planned. Their object was primarily to furnish a basis of comparison for the observations made with the same instruments during the eclipse, but they also furnish a means of determining the intensity of the solar heat on the days upon which the readings were made. They are of especial interest on account of the position of the observing station.

Two kinds of instruments were employed, furnished through the kindness of the Chief Signal Officer.

1. *Conjugate thermometers of the* MARIÉ-DAVY *pattern.*—These were made especially for the expedition by Messrs. J. & H. J. GREEN, New York, and consisted of a black and bright bulb thermometer, each inclosed in a vacuum,* the inclosure being spherical in shape where it surrounded the bulb of the thermometer. The diameter of the inclosure was 2.15 inches, the bulb being centrally situated within it. The thermometers themselves were of the ordinary pattern with large gradnations on the Fahrenheit scale. Instruments of this class are sometimes made with maximum thermometers, but this is very inconvenient where readings are to be made at stated times during the day. Two pairs of instruments were used, numbered 1, 2, 3, and 4 by the makers.

2. VIOLLE'S *conjugate bulbs.*—These consisted of two hollow copper spheres 1.04 inches in diameter, one blackened, the other gilt. In each was placed a thermometer graduated to half degrees centigrade, with its bulb blackened and located centrally within the sphere.*

In addition to these special instruments, two ordinary thermometers, GREEN 1136 and 1137, were exposed in the sun, with the bulb of the latter blackened. The difference of the readings of these thermometers is an approximate measure of the solar radiation, but the result does not have the value of either of the other methods.

The conjugate thermometers were mounted upon brass supports 7 inches high, and each pair of supports was screwed to a board painted black. The boards were placed upon the ground in an open grassy spot selected with especial care for these observations. The thermometers were nearly horizontal, but sufficiently inclined, bulb downward, to secure an unbroken column of mercury. The inclosures of the thermometers constituting a pair faced each other at a distance of several inches, the white bulb toward the east. The board containing the instruments was turned at frequent intervals during the day in order that they might have approximately the same position with regard to the sun. The VIOLLE bulbs were mounted each upon a wooden stand 10 inches above the ground, with the stems of the thermometers projecting horizontally toward the south or opposite the sun. The ordinary thermometers were exposed horizontally, each attached by a brass support to the corresponding thermometer of the conjugate pair, and situated a couple inches above it. The instruments thus placed were in a favorable position for the desired observations, which were made hourly or oftener upon every clear day during the stay upon Caroline Island, beginning with April 27.

*The instruments devised by Marié-Davy are described in the Bulletin Mensuel de l'Obs. Phys. Central de Montsouris, 1873, p. 80, and 1874, pp. 134 and 189.

*A full description of these instruments, with the formula for reducing the readings, is given in "Sur la Radiation Solaire," by M. J. VIOLLE, Paris, 1879.

The following table contains the observations in detail:

FRIDAY, APRIL 27.

| Time. | Conjugate thermometers. | | | | VIOLLE's bulbs. | | Ordinary thermometers. | | Remarks. |
|---|---|---|---|---|---|---|---|---|---|
| | Black. | | Bright. | | Black. No. 742. | Gilt. No. 751. | Black. No. 1137. | Bright. No. 1136. | |
| | No. 4. | No. 3. | No. 2. | No. 1. | | | | | |
| A. M. | | | | | | | | | |
| 7.00 | 94.3 | - - - | 85.7 | - - - | - - - | - - - | - - - - | - - - - | Sun just entering cloud. |
| 8.00 | 81.2 | - - - | 78.6 | - - - | - - - | - - - | - - - - | - - - - | Sprinkling; bulbs wet. |
| 9.00 | 130.0 | - - - | 105.1 | - - - | - - - | - - - | 95.0 | 88.2 | Sun clear. |
| 10.00 | 110.1 | - - - | 96.1 | - - - | - - - | - - - | 89.2 | 86.0 | Sun behind clouds. |
| 11.00 | 134.0 | - - - | 108.7 | - - - | - - - | - - - | 95.7 | 90.0 | Sun behind thin cir. str. clouds. |
| 12.00 | 141.6 | - - - | 115.7 | - - - | 42.4 | 34.8 | 98.0 | 93.0 | Do. |
| P. M. | | | | | | | | | |
| 12.10 | 142.9 | 144.9 | 114.9 | 112.8 | 40.8 | 34.8 | 101.7 | 95.3 | Sun clear. |
| 12.12 | 144.7 | 146.3 | 115.7 | 113.8 | 41.3 | 34.9 | 103.5 | 96.2 | Do. |
| 12.15 | 144.9 | 146.9 | 116.0 | 114.2 | 41.2 | 35.1 | 102.0 | 96.5 | Do. |
| 1.00 | 141.7 | 144.5 | 114.5 | 112.3 | 42.5 | 37.8 | 102.0 | 95.0 | Sun behind thin cir. str. clouds. |
| 2.00 | 138.7 | 139.8 | 113.4 | 111.6 | 42.7 | 38.1 | 100.8 | 94.8 | Do. |
| 3.00 | 133.0 | 132.4 | 110.1 | 108.3 | 42.5 | 37.7 | 100.3 | 93.5 | Do. |
| 4.00 | 126.9 | 126.9 | 105.7 | 104.3 | 41.2 | 36.4 | 95.0 | 89.5 | Do. |
| 5.00 | 86.2 | 86.8 | 83.4 | 83.6 | 28.4 | 28.8 | 83.2 | 82.7 | Sun behind clouds. |

*Summary.*—Poor day. Sun clear at 9.00 a. m. and 12.10 to 12.15 p. m. only.

SATURDAY, APRIL 28.

| Time. | Conjugate thermometers. | | | | VIOLLE's bulbs. | | Ordinary thermometers. | | Remarks. |
|---|---|---|---|---|---|---|---|---|---|
| | Black. | | Bright. | | Black. No. 742. | Gilt. No. 751. | Black. No. 1137. | Bright. No. 1136. | |
| | No. 4. | No. 3. | No. 2. | No. 1. | | | | | |
| A. M. | | | | | | | | | |
| 7.40 | - - - | 123.8 | - - - | 99.7 | 38.8 | 35.1 | 95.3 | 87.0 | Sun in thin haze. |
| 8.00 | 114.0 | 115.3 | 94.9 | 95.6 | 34.8 | 32.1 | 97.2 | 89.0 | Sun emerging from cloud. |
| 9.00 | 137.0 | 139.3 | 108.1 | 108.0 | 40.8 | 36.4 | 97.4 | 90.3 | Sun clear. |
| 9.30 | 136.5 | 139.2 | 108.9 | 108.5 | 41.1 | 36.6 | 100.5 | 92.0 | Do. |
| 9.35 | 137.6 | 140.3 | 109.8 | 109.4 | 41.8 | 37.2 | 100.0 | 92.0 | Do. |
| 10.00 | 137.3 | 140.0 | 109.9 | 109.2 | 41.0 | 36.3 | 100.7 | 91.4 | Do. |
| 10.30 | 136.4 | 140.2 | 110.1 | 110.2 | 42.9 | 37.9 | 102.0 | 93.8 | Do. |
| 10.35 | 138.0 | 141.8 | 111.1 | 111.1 | 43.0 | 38.2 | 102.3 | 94.2 | Do. |
| 11.00 | 140.6 | 141.1 | 114.0 | 113.7 | 43.8 | 38.7 | 102.5 | 94.3 | Do. |
| 11.30 | 140.1 | 143.2 | 113.9 | 114.3 | 43.4 | 38.6 | 101.0 | 94.0 | Do. |
| 12.00 | 143.2 | 146.2 | 115.0 | 114.9 | 44.4 | 39.2 | 105.0 | 96.2 | Do. |
| P. M. | | | | | | | | | |
| 12.30 | 147.0 | 149.2 | 118.2 | 118.2 | 46.3 | 40.4 | 106.5 | 97.5 | Do. |
| 1.00 | 143.2 | 143.9 | 116.5 | 116.5 | 45.2 | 39.7 | 104.0 | 96.8 | Do. |
| 1.30 | 141.0 | 141.5 | 116.2 | 115.5 | 45.1 | 39.6 | 103.2 | 96.0 | Do. |
| 2.00 | 143.1 | 146.5 | 119.3 | 118.0 | 47.6 | 42.0 | 105.5 | 99.0 | Sun behind thin clouds. |
| 2.08 | 145.0 | 148.3 | 120.1 | 118.8 | 48.5 | 42.0 | 107.0 | 99.8 | Sun clear; clouds immediately afterward. |
| 2.15 | 145.9 | 148.5 | 118.0 | 117.8 | 46.0 | 40.4 | 106.2 | 97.7 | Sun clear. |
| 2.22 | 148.5 | 150.2 | 118.8 | 117.0 | 45.1 | 39.8 | 105.2 | 96.8 | Sun clear just before entering cloud. |
| 2.30 | 133.6 | 135.8 | 109.8 | 109.0 | 40.9 | 36.7 | 103.2 | 95.5 | Sun clear, but in clouds just before and after. |
| 3.00 | 137.8 | 139.9 | 111.6 | 110.6 | 43.1 | 37.8 | 102.3 | 94.8 | Sun behind thin clouds. |
| 3.30 | 134.6 | 137.8 | 109.0 | 108.8 | 41.5 | 36.8 | 99.5 | 92.2 | Do. |
| 4.00 | 127.7 | 130.4 | 113.6* | 104.5 | 39.7 | 35.7 | 96.8 | 90.0 | Sun clear. |
| 4.30 | 121.0 | - - - | 98.0 | - - - | 37.6 | 34.2 | - - - - | - - - - | Do. |
| 5.00 | 105.0 | 107.2 | 92.0 | 91.6 | 32.8 | 32.0 | 86.0 | 83.8 | Sun just entering cloud. |

* Should be 103.6.

*Summary.*—Sun clear 9.00 a. m. to 2.00 p. m. The p. m. observations affected by passing clouds. Two maxima indicated, at about 12.30 and 2.30 p. m.

SUNDAY, APRIL 29.

| Time. | Conjugate thermometers. Black. No. 4. | Conjugate thermometers. Black. No. 3. | Conjugate thermometers. Bright. No. 2. | Conjugate thermometers. Bright. No. 1. | VIOLLE'S bulbs. Black. No. 742. | VIOLLE'S bulbs. Gilt. No. 751. | Ordinary thermometers. Black. No. 1137. | Ordinary thermometers. Bright. No. 1136. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|
| A. M. | | | | | | | | | |
| 6.40 | 89.8 | 89.9 | 83.8 | 83.6 | 28.4 | 28.1 | 85.3 | 81.4 | Sun in thin clouds. |
| 6.50 | 90.6 | 91.2 | 84.0 | 84.2 | 28.7 | 28.1 | 85.5 | 82.7 | Sun in clouds. |
| 6.55 | 101.8 | 102.7 | 88.7 | 88.5 | 31.0 | 29.5 | 89.5 | 84.5 | Sun almost clear; clouds follow. |
| 7.48 | 124.5 | 125.1 | 100.5 | 99.2 | 36.7 | 33.5 | - - - | - - - | Sun in thin haze. |
| 7.54 | 126.6 | 125.9 | 100.9 | 100.5 | 37.9 | 31.3 | - - - | - - - | Do. |
| 8.00 | 128.1 | 127.0 | 100.7 | 101.3 | 38.8 | 35.1 | - - - | - - - | Do. |
| 8.30 | 131.7 | 130.3 | 103.3 | 103.0 | 38.8 | 35.4 | - - - | - - - | Sun just entering cloud. |
| 8.40 | 131.7 | 130.5 | 103.5 | 104.2 | 38.8 | 35.4 | - - - | - - - | Sun clear. |
| 9.00 | 135.0 | 133.5 | 105.4 | 106.6 | 39.7 | 36.0 | 97.5 | 90.5 | Do. |
| 9.20 | 138.5 | 136.3 | 107.2 | 108.7 | 40.5 | 36.6 | 100.3 | 92.1 | Do. |
| 9.30 | 139.7 | 137.5 | 108.1 | 109.6 | 41.0 | 37.0 | 100.3 | 92.3 | Sun clear, but just out of clouds. |
| 9.35 | 140.8 | 138.7 | 108.9 | 110.2 | 41.4 | 37.4 | 101.2 | 93.3 | Sun clear or in haze. |
| 10.00 | 144.2 | 142.7 | 111.9 | 112.8 | 43.1 | 38.9 | 104.0 | 95.0 | Do. |
| 10.30 | 150.5 | 149.9 | 116.2 | 116.5 | 45.5 | 40.5 | 108.8 | 97.8 | Sun just entering cloud |
| 11.00 | 142.0 | 142.5 | 112.4 | 112.1 | 45.6 | 38.2 | 101.0 | 94.0 | Sun clear. |
| 11.15 | 143.5 | 145.1 | 114.6 | 113.8 | 45.6 | 38.7 | 105.2 | 96.7 | Do. |
| 11.30 | 144.0 | 146.6 | 115.7 | 114.4 | 45.6 | 39.9 | 105.5 | 97.5 | Do. |
| 11.45 | 144.0 | 147.3 | 116.0 | 114.8 | 45.6 | 39.5 | 107.0 | 97.8 | Do. |
| 12.00 | 143.2 | 146.2 | 115.8 | 115.0 | 45.5 | 39.9 | 106.8 | 98.0 | Do. |
| P. M. | | | | | | | | | |
| 12.15 | 143.7 | 147.0 | 116.2 | 115.3 | 45.5 | 39.8 | 107.7 | 98.0 | Do. |
| 12.30 | 144.0 | 147.0 | 116.9 | 116.0 | 45.5 | 40.2 | 106.5 | 98.0 | Do. |
| 1.03 | 117.7 | 149.2 | 119.1 | 118.7 | 46.5 | 41.1 | 108.2 | 100.0 | Sun clear. Max. readings after clouds. |
| 1.30 | 141.0 | 140.7 | 115.6 | 114.9 | 46.0 | 39.5 | 105.7 | 98.0 | Sun clear. |
| 2.10 | 138.0 | 139.8 | 115.1 | 114.2 | 46.0 | 39.7 | 101.0 | 96.0 | Do. |
| 2.30 | 135.5 | 140.5 | 114.4 | 113.5 | 46.0 | 39.7 | 101.8 | 96.5 | Do. |
| 3.00 | 139.0 | 137.9 | 112.2 | 112.0 | 46.0 | 39.2 | 102.0 | 95.5 | Do. |
| 3.30 | 135.0 | 133.0 | 109.8 | 109.0 | 45.9 | 38.3 | 99.2 | 94.0 | Do. |

*Summary.*—Troubled by passing clouds throughout the day, though generally clear when readings were made.

MONDAY, APRIL 30.

| Time. | Conjugate thermometers. Black. No. 4. | Conjugate thermometers. Black. No. 3. | Conjugate thermometers. Bright. No. 2. | Conjugate thermometers. Bright. No. 1. | VIOLLE'S bulbs. Black. No. 742. | VIOLLE'S bulbs. Gilt. No. 751. | Ordinary thermometers. Black. No. 1137. | Ordinary thermometers. Bright. No. 1136. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|
| A. M. | | | | | | | | | |
| 7.00 | - - - | 111.8 | - - - | 92.9 | 33.6 | 31.2 | 88.2 | 84.2 | Sun clear. |
| 7.15 | 114.1 | 116.7 | 94.8 | 95.1 | 34.7 | 32.1 | 89.8 | 85.2 | Do. |
| 7.30 | 121.8 | 121.7 | 98.9 | 97.8 | 36.2 | 33.2 | 92.4 | 86.3 | Sun clear; cloudy 7.45–8.00 a. m. |
| 8.05 | 122.0 | 122.5 | 99.1 | 98.5 | 38.0 | 34.0 | 97.5 | 89.2 | Do. |
| 8.20 | 134.0 | 134.9 | *116.5 | *114.9 | 41.5 | 37.1 | 98.2 | 90.3 | Do. |
| 8.55 | 135.1 | 136.5 | 107.2 | 106.5 | 43.0 | 38.0 | 99.2 | 92.5 | Do. |
| 9.00 | 138.2 | 139.5 | 109.5 | 108.3 | 43.9 | 38.9 | 101.7 | 92.5 | Do. |
| 9.30 | 143.3 | 145.5 | 113.2 | 112.7 | 46.5 | 40.2 | 105.0 | 95.0 | Do. |
| 10.00 | 99.3 | 100.8 | 92.9 | 92.1 | 33.6 | 33.8 | 86.0 | 85.0 | Sun in heavy clouds for ten minutes before. |
| 10.30 | 128.3 | 139.7 | 109.5 | 109.1 | 43.8 | 35.4 | 101.2 | 93.3 | Sun clear; rain drops on bulbs |
| 10.45 | 147.0 | 145.9 | 113.7 | 114.8 | 46.2 | 40.6 | 108.7 | 98.2 | Sun clear. |
| 11.00 | 148.2 | 147.5 | 115.4 | 116.7 | 46.7 | 42.6 | 109.1 | 99.0 | Do. |
| 11.30 | 148.8 | 149.0 | 117.2 | 117.5 | 46.2 | 41.8 | 105.5 | 98.0 | Do. |
| 11.45 | 147.9 | 149.0 | 117.2 | 117.3 | 45.4 | 40.8 | 109.3 | 99.5 | Do. |
| 12.00 | 148.0 | 149.8 | 117.8 | 117.9 | 46.5 | 41.9 | 110.0 | 100.5 | Do. |
| P. M. | | | | | | | | | |
| 12.15 | 147.3 | 149.2 | 117.8 | 117.3 | 45.5 | 40.5 | 109.4 | 99.8 | Do. |
| 12.20 | Instruments taken away on account of wind squall and expected rain. | | | | | | | | Brought out at 2.00 p. m. |
| 3.00 | 136.8 | 137.7 | 109.5 | 109.2 | 41.7 | 37.4 | 98.5 | 93.0 | Sun clear. |
| 3.30 | 133.1 | 134.2 | 107.2 | 106.8 | 39.8 | 35.5 | 98.3 | 91.5 | Do. |
| 4.00 | 129.1 | 129.8 | 104.8 | 103.9 | 39.5 | 35.9 | 97.5 | 90.5 | Do. |
| 4.30 | 122.5 | 122.2 | 100.9 | 99.5 | 36.7 | 34.2 | 93.5 | 87.5 | Do. |
| 5.00 | 113.8 | 113.0 | 96.0 | 94.7 | 35.2 | 32.4 | 85.2 | 86.0 | Do. |

*Probably should be 106.5, 104.9.

*Summary.*—Good weather, especially in p. m.

TUESDAY, MAY 1.

| Time. | Conjugate thermometers. | | | | VIOLLE's bulbs. | | Ordinary thermometers. | | Remarks. |
|---|---|---|---|---|---|---|---|---|---|
| | Black. | | Bright. | | Black. No. 742. | Gilt. No. 751. | Black. No. 1137. | Bright. No. 1136. | |
| | No. 4. | No. 3. | No. 2. | No. 1. | | | | | |
| A. M. | | | | | | | | | |
| 6.30 | 91.3 | 91.7 | 84.0 | 84.0 | 28.8 | 28.3 | 83.8 | 82.0 | Sun clear; perhaps in haze. |
| 6.35 | 96.7 | 97.8 | 85.9 | 86.2 | 30.2 | 29.1 | 85.2 | 82.5 | Do. |
| 6.40 | 100.1 | 101.6 | 86.9 | 87.7 | 31.2 | 29.7 | 86.5 | 83.0 | Do. |
| 6.45 | 102.9 | 104.3 | 86.9 | 89.0 | 31.9 | 30.2 | 86.7 | 83.5 | Do. |
| 6.50 | 105.2 | 106.9 | 88.8 | 90.0 | 32.2 | 30.5 | 87.2 | 83.5 | Do. |
| 6.55 | 107.5 | 109.3 | 90.8 | 91.2 | 32.6 | 30.7 | 88.5 | 83.8 | Do. |
| 7.00 | 109.8 | 111.6 | 92.3 | 92.2 | 33.5 | 31.3 | 89.2 | 84.5 | Sun clear. |
| 7.15 | 114.5 | 117.0 | 95.5 | 95.0 | 34.4 | 32.0 | 90.5 | 85.2 | Do. |
| 7.30 | 121.8 | 122.8 | 99.5 | 99.0 | 37.5 | 34.1 | 92.2 | 87.0 | Do. |
| 8.30 | 129.2 | 130.5 | 101.8 | 105.0 | 40.8 | 36.5 | 98.0 | 92.0 | Do. |
| 8.45 | 133.3 | 137.0 | 107.5 | 107.5 | 41.8 | 37.5 | 98.2 | 91.2 | Do. |
| 9.00 | *126.0 | 135.0 | 108.3 | 107.8 | 42.6 | 38.4 | 99.5 | 92.5 | Do. |
| 9.30 | 138.0 | 138.8 | 109.8 | 110.0 | 44.0 | 39.6 | 101.2 | 94.0 | Do. |
| 10.00 | 140.9 | 141.3 | 111.5 | 113.0 | 44.6 | 40.0 | 103.0 | 95.0 | Do. |
| 10.30 | 143.5 | 143.9 | 112.5 | 115.0 | 44.8 | 39.9 | 103.5 | 96.0 | Do. |
| 11.00 | 146.0 | 147.0 | 114.0 | 116.8 | 46.9 | 41.8 | 106.5 | 99.2 | Do. |
| 12.00 | 147.9 | 149.3 | 111.0 | 117.5 | 47.2 | 41.6 | 106.5 | 99.3 | Do. |
| P. M. | | | | | | | | | |
| 1.00 | 146.3 | †150.2 | 114.5 | 117.3 | 46.7 | 41.3 | 107.5 | 99.2 | Do. |
| 2.00 | 144.2 | 145.0 | 112.2 | 115.5 | 46.2 | 40.7 | 106.2 | 97.0 | Do. |
| 3.00 | 139.2 | 136.5 | 108.5 | 111.5 | 45.1 | 40.3 | 102.6 | 95.0 | Sun behind thin cir. str. |
| 3.40 | 132.5 | 129.8 | 103.2 | 107.7 | 43.0 | 38.7 | 99.5 | 92.5 | Do. |

*Reservoir partly in shade of the stem.

†Probably the maximum reading before 1.00 p. m., as the column was found broken at 2.00 p. m.

*Summary.*—Observations in early a. m. were made frequently. Up to 3.00 p. m. all readings are unusually good.

WEDNESDAY, MAY 2.

| Time. | Conjugate thermometers. | | | | VIOLLE's bulbs. | | Ordinary thermometers. | | Remarks. |
|---|---|---|---|---|---|---|---|---|---|
| | Black. | | Bright. | | Black. No. 742. | Gilt. No. 751. | Black. No. 1137. | Bright. No. 1136. | |
| | No. 4. | No. 3. | No. 2. | No. 1. | | | | | |
| A. M. | | | | | | | | | |
| 6.30 | 90.2 | 91.0 | 83.5 | 84.0 | 28.0 | 28.2 | 83.3 | 82.0 | Sun behind thin clouds. |
| 7.00 | 110.8 | 111.2 | 93.8 | 93.0 | 32.9 | 30.8 | 87.2 | 84.0 | Sun clear. |
| 7.40 | 122.6 | 121.0 | 98.2 | 99.0 | 38.0 | 34.9 | 91.2 | 87.0 | Do. |
| 8.00 | 131.2 | 127.5 | 102.8 | 102.7 | 40.3 | 36.5 | 94.5 | 89.0 | Do. |
| 8.30 | 127.9 | 124.9 | 102.8 | 102.8 | 39.8 | 36.5 | 98.2 | 91.0 | Sun clear, but just emerged from clouds. |
| 9.00 | 137.8 | 135.0 | 107.9 | 108.4 | 42.0 | 38.0 | 101.0 | 92.5 | Sun clear, but emerged from clouds five minutes before. |
| 10.00 | 145.0 | 143.0 | 113.5 | 114.3 | 45.6 | 40.5 | 104.7 | 96.0 | Sun clear. |
| 10.30 | 146.9 | 144.8 | 115.1 | 115.2 | 45.5 | 40.8 | 103.0 | 95.8 | Do. |
| 10.45 | 147.5 | 145.5 | 115.2 | 115.3 | 45.9 | 41.0 | 105.4 | 96.5 | Do. |
| 11.00 | 148.2 | 147.0 | 116.0 | 116.2 | 46.3 | 41.3 | 106.0 | 97.0 | Do. |
| 11.15 | 149.0 | 148.5 | 116.4 | 117.0 | 47.0 | 41.7 | 107.7 | 98.5 | Do. |
| 11.30 | 148.9 | 149.3 | 116.5 | 116.8 | 46.9 | 41.7 | 109.2 | 98.5 | Do. |
| 12.00 | 148.0 | 148.9 | 115.8 | 116.5 | 46.2 | 41.1 | 106.0 | 97.7 | Do. |
| P. M. | | | | | | | | | |
| 12.30 | 148.0 | 149.2 | 115.8 | 117.2 | 46.0 | 41.6 | 107.2 | 98.5 | Do. |
| 1.00 | 147.4 | 149.2 | 116.2 | 117.8 | 47.9 | 42.6 | 109.0 | 98.5 | Do. |
| 2.00 | 144.5 | 145.5 | 115.5 | 117.0 | 49.1 | 43.6 | 107.2 | 98.8 | Do. |
| 2.30 | 141.7 | 141.0 | 114.0 | 114.8 | 47.8 | 42.7 | 104.5 | 97.5 | Do. |
| 3.00 | *138.7 | 143.7 | 110.0 | 113.2 | 47.5 | 42.4 | 104.2 | 95.5 | Do. |
| 3.30 | 135.0 | 139.6 | 107.2 | 109.4 | 44.8 | 40.4 | 102.8 | 94.0 | Do. |
| 4.00 | 131.5 | 135.0 | †115.5 | 106.0 | 43.9 | 39.6 | 101.0 | 92.5 | Do. |
| 4.30 | 124.5 | 127.0 | 102.5 | 100.8 | 40.0 | 36.8 | 97.4 | 88.5 | Do. |
| 4.45 | 120.0 | 120.7 | 100.0 | 98.0 | 37.0 | 34.1 | 93.0 | 87.0 | Do. |
| 5.00 | 116.0 | 116.0 | 97.7 | 95.8 | 35.9 | 33.3 | 91.5 | 86.5 | Do. |

* Bulb close to grass blade. † Should be 105.5.

*Summary.*—Sky almost wholly clear after 9.00 a. m. The p. m. observations are especially good.

THURSDAY, MAY 3.

| Time. | Conjugate thermometers. | | | | VIOLLE's bulbs. | | Ordinary thermometers. | | Remarks. |
|---|---|---|---|---|---|---|---|---|---|
| | Black. | | Bright. | | Black. No. 742. | Gilt. No. 751. | Black. No. 1137. | Bright. No. 1136. | |
| | No. 4. | No. 3. | No. 2. | No. 1. | | | | | |
| A. M. | | | | | | | | | |
| 7.00 | 106.8 | 106.6 | 91.0 | 90.1 | 33.2 | 30.8 | 89.5 | 81.5 | Sun clear. |
| 7.30 | 114.2 | 111.1 | 96.0 | 95.0 | 35.1 | 33.2 | 88.5 | 85.0 | Sun partly clear; in clouds just before. |
| 8.30 | 131.2 | 130.9 | 104.1 | 104.2 | 40.6 | 37.0 | 96.2 | 89.8 | Sun clear; in clouds at 8.00 a. m. |
| 9.00 | 136.2 | 136.0 | 107.5 | 108.0 | 41.6 | 37.5 | 99.5 | 92.0 | Sun just entering cloud. |
| 10.30 | 143.6 | 142.2 | 112.0 | 113.3 | 43.6 | 38.7 | 104.0 | 96.0 | Sun clear. |
| 11.00 | 147.5 | 148.0 | 114.9 | 116.2 | 44.2 | 39.2 | 104.0 | 96.3 | Do. |
| 11.30 | 146.7 | 147.9 | 114.5 | 115.6 | 44.5 | 39.5 | 105.5 | 97.0 | Do. |
| 12.00 | 146.9 | 148.7 | 115.1 | 116.0 | 44.9 | 39.8 | 105.5 | 97.5 | Do. |
| P. M. | | | | | | | | | |
| 12.30 | 146.6 | 148.2 | 115.1 | 116.6 | 45.2 | 40.0 | 106.0 | 98.0 | Do. |
| 1.00 | 146.0 | 148.1 | 115.5 | 117.0 | 45.9 | 40.5 | 107.3 | 98.0 | Do. |
| 1.30 | 147.5 | 147.1 | 116.0 | 116.9 | 46.2 | 41.0 | 106.5 | 98.7 | Do. |
| 2.00 | 144.7 | 145.0 | 114.0 | 115.2 | 44.8 | 39.8 | 106.0 | 97.2 | Do. |
| 2.30 | 140.8 | 141.0 | 111.0 | 112.6 | 43.9 | 39.1 | 103.0 | 96.0 | Sun just entering cloud. |

*Summary.*—Sky not wholly clear. Observations before 10.30 a. m. and after 2.00 p. m. were interfered with by passing clouds. Between these times readings are reliable.

No radiation observations were made May 4 on account of clouds.

SATURDAY, MAY 5.

| Time. | Conjugate thermometers. | | | | VIOLLE's bulbs. | | Ordinary thermometers. | | Remarks. |
|---|---|---|---|---|---|---|---|---|---|
| | Black. | | Bright. | | Black. No. 742. | Gilt. No. 751. | Black. No. 1137. | Bright. No. 1136. | |
| | No. 4. | No. 3. | No. 2. | No. 1. | | | | | |
| A. M. | | | | | | | | | |
| 8.30 | 129.2 | 126.8 | 103.5 | 101.2 | 36.1 | 33.4 | 92.2 | 88.0 | Sun in haze. |
| 10.00 | 137.5 | 137.2 | 109.5 | 109.2 | 39.7 | 35.7 | 98.0 | 91.8 | Sun clear. |
| 10.30 | 142.6 | 142.5 | 112.5 | 112.3 | 41.7 | 37.2 | 99.8 | 93.2 | Do. |
| 11.00 | 142.0 | 142.5 | 111.7 | 111.9 | 40.8 | 36.3 | 100.8 | 93.7 | Do. |
| 11.30 | 143.0 | 141.5 | 112.0 | 112.5 | 41.4 | 36.7 | 101.3 | 95.0 | Do. |
| 12.00 | 143.0 | 141.6 | 112.0 | 113.0 | 41.1 | 36.5 | 102.5 | 95.0 | Sun just out of cir. str. clouds. |

*Summary.*—Sky cloudy nearly all day, but the few readings made are reliable.

SUNDAY, MAY 6.

| Time. | Conjugate thermometers. Black. No. 3. | Conjugate thermometers. Bright. No. 1. | VIOLLE's bulbs. Black. No. 742. | VIOLLE's bulbs. Gilt. No. 751. | Ordinary thermometers. Black. No. 1137. | Ordinary thermometers. Bright. No. 1136. | Remarks. |
|---|---|---|---|---|---|---|---|
| A. M. | | | | | | | |
| 9.45 | 125.2 | 98.8 | 35.1 | 31.8 | 94.0 | 87.5 | Sun clear, but just emerged from clouds. |
| 9.57 | 137.0 | 105.1 | 38.3 | 34.8 | 95.2 | 89.2 | Sun clear. |
| 10.35 | 131.0 | 104.3 | 37.1 | 34.4 | 94.0 | 88.8 | Sun clear, in partial eclipse. |
| P. M. | | | | | | | |
| 12.35 | 121.0 | 99.7 | 35.8 | 33.3 | 94.2 | 90.0 | Do. |
| 12.50 | 130.4 | 105.0 | 37.7 | 34.5 | 97.0 | 90.8 | Do. |
| 1.02 | 136.3 | 108.5 | 39.2 | 35.5 | 98.3 | 91.7 | Do. |
| 1.15 | 139.0 | 110.3 | 39.7 | 36.0 | 98.2 | 91.5 | Sun clear. |
| 1.30 | 139.0 | 110.9 | 39.8 | 36.1 | 98.8 | 91.8 | Do. |
| 2.00 | 135.6 | 110.2 | 39.7 | 36.0 | 98.3 | 91.5 | Do. |
| 2.30 | 133.6 | 109.3 | 40.5 | 36.5 | 97.2 | 91.3 | Sun just out of clouds. |
| 2.32 | 134.9 | 109.6 | 40.5 | 36.5 | 99.2 | 91.3 | Sun clear. Max. values before again obscured. |
| 2.45 | 138.2 | 108.9 | 40.1 | 36.3 | 96.8 | 90.7 | Sun clear. |
| 3.00 | 136.7 | 107.3 | 39.5 | 35.8 | 97.2 | 91.2 | Do. |
| 3.15 | 134.5 | 105.7 | 38.6 | 35.3 | 95.7 | 90.0 | Do. |
| 3.45 | 129.5 | 102.7 | 37.7 | 34.4 | 95.3 | 89.5 | Sun behind thin clouds. Cloudy at 3.00 p. m. |
| 3.50 | 132.9 | 103.8 | 38.5 | 34.9 | 96.5 | 89.2 | Sun clear. |
| 4.00 | 126.2 | 101.0 | 36.8 | 33.8 | 93.5 | 88.2 | Sun in haze. |
| 4.15 | 122.3 | 101.0 | 36.1 | 33.4 | 92.3 | 87.4 | Sun clear, but whole sky is hazy. |
| 4.30 | 117.2 | 98.5 | 34.8 | 32.6 | 91.2 | 86.7 | Sun in haze. |
| 4.50 | 110.2 | 94.6 | 32.9 | 31.4 | 88.7 | 85.3 | Do. |
| 5.00 | 109.2 | 93.8 | 32.8 | 31.2 | 87.6 | 85.0 | Do. |

*Summary.*—Cloudy until 9.45 a. m., and at intervals throughout the day. [Special observations made from 10.00 a. m. to 1.15 p. m. are given below.]

## *Special observations in connection with solar eclipse.*

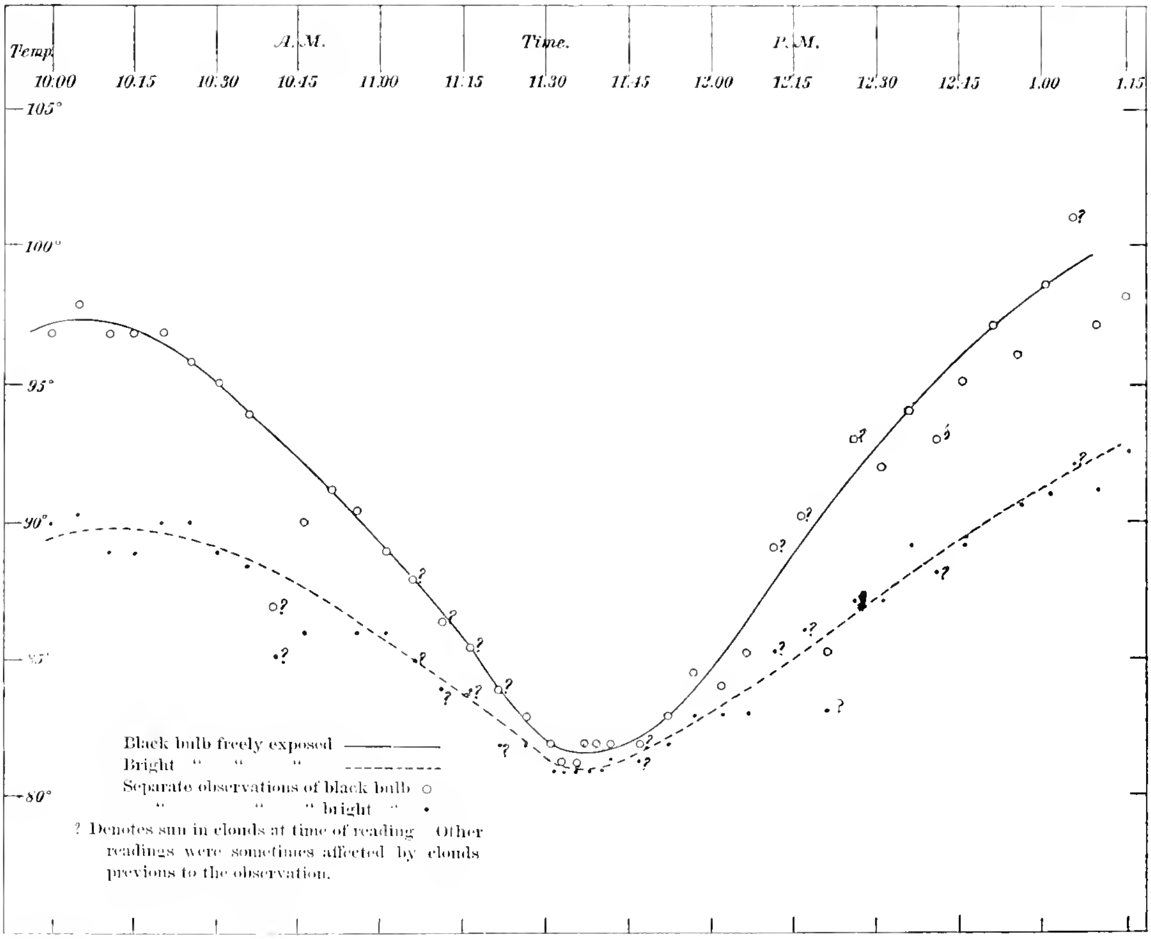
J. C. HAROLD, observer.

SUNDAY, MAY 6.

| Time. | Conjugate thermometers. Black. No. 3. | Conjugate thermometers. Bright. No. 1. | VIOLLE's bulbs. Black. No. 742. | VIOLLE's bulbs. Gilt. No. 751. | Ordinary thermometers. Black. No. 1137. | Ordinary thermometers. Bright. No. 1136. | Remarks. |
|---|---|---|---|---|---|---|---|
| A. M. | | | | | | | |
| 10.00 | 137.5 | 106.0 | 38.5 | 35.0 | 97.0 | 90.0 | Sun clear. |
| 10.05 | 138.5 | 106.5 | 39.5 | 35.5 | 98.0 | 90.5 | Do. |
| 10.10 | 139.0 | 107.0 | 39.5 | 35.5 | 97.0 | 89.0 | Do. |
| 10.15 | 138.0 | 107.0 | 39.0 | 35.5 | 97.0 | 89.0 | Do. |
| 10.20 | 137.0 | 107.0 | 39.0 | 35.5 | 97.0 | 90.0 | Do. |
| 10.25 | 136.0 | 106.0 | 38.5 | 35.5 | 96.0 | 90.0 | Do. |
| 10.30 | 133.5 | 105.5 | 38.0 | 35.0 | 95.0 | 89.0 | Do. |
| 10.35 | 131.0 | 104.5 | 37.0 | 34.5 | 94.0 | 88.5 | Do. |
| 10.40 | 124.0 | 101.0 | 36.0 | 34.0 | 87.0 | 88.5 | Sun in cloud. |
| 10.45 | 113.5 | 96.0 | 33.0 | 32.0 | 90.0 | 86.0 | Sun clear. |
| 10.50 | 115.5 | 97.0 | 33.5 | 32.0 | 91.5 | 87.0 | Do. |
| 10.55 | 115.0 | 97.0 | 34.0 | 32.0 | 90.5 | 86.0 | Do. |
| 11.00 | 113.0 | 96.0 | 33.5 | 32.0 | 89.0 | 86.0 | Do. |
| 11.05 | 109.0 | 94.0 | 32.5 | 31.5 | 88.0 | 85.0 | Sun in cloud. |
| 11.10 | 104.5 | 92.0 | 31.5 | 30.5 | 86.5 | 84.0 | Do. |
| 11.15 | 100.6 | 90.0 | 30.5 | 30.0 | 85.5 | 81.0 | Do. |
| 11.20 | 99.5 | 87.0 | 28.5 | 28.5 | 84.0 | 82.0 | Do. |
| 11.25 | 90.0 | 85.0 | 28.5 | 28.5 | 83.0 | 82.0 | Sun clear. |
| 11.30 | 86.0 | 83.0 | 27.5 | 28.0 | 82.0 | 81.0 | Do. |
| 11.32 | 85.0 | 82.0 | 26.5 | 28.0 | 81.5 | 81.0 | Total phase of eclipse. Lantern used. |
| 11.34 | 84.9 | 82.0 | 27.0 | 28.0 | 81.5 | 81.0 | |
| 11.36 | 82.0 | 82.0 | 27.0 | 28.0 | 82.0 | 81.0 | |
| 11.38 | 82.0 | 82.0 | 27.0 | 28.0 | 82.0 | 81.0 | |

Fig. 19.

CURVES OF BLACK AND BRIGHT BULB THERMOMETERS DURING ECLIPSE.



*Special observations in connection with solar eclipse*—Continued.

SUNDAY, MAY 6—Continued.

| Time. | Conjugate thermometers. | | VIOLLE's bulbs. | | Ordinary thermometers. | | Remarks. |
|---|---|---|---|---|---|---|---|
| | Black. No. 3. | Bright. No. 1. | Black. No. 742. | Gilt. No. 751. | Black. No. 1137. | Bright. No. 1136. | |
| A. M. | | | | | | | |
| 11.40 | 82.0 | 81.0 | 27.0 | 27.5 | 82.0 | 81.5 | Sun clear. |
| 11.45 | 82.0 | 81.0 | 27.0 | 27.5 | 82.0 | 81.5 | Sun in cloud |
| 11.50 | 84.0 | 82.0 | 27.5 | 28.0 | 83.0 | 82.0 | Sun clear. |
| 11.55 | 88.0 | 84.0 | 28.5 | 28.5 | 84.5 | 83.0 | Do. |
| 12.00 | 90.0 | 85.0 | 29.0 | 28.5 | 84.0 | 83.0 | Do. |
| P. M. | | | | | | | |
| 12.05 | 93.0 | 86.0 | 29.5 | 29.0 | 85.0 | 83.0 | Do. |
| 12.10 | 99.0 | 89.0 | 30.5 | 30.0 | 89.0 | 85.0 | Sun in cloud. |
| 12.15 | 101.0 | 90.0 | 31.5 | 30.5 | 90.0 | 86.0 | Do. |
| 12.20 | 98.0 | 89.0 | 31.0 | 30.5 | 85.0 | 83.0 | Do. |
| 12.25 | 109.0 | 94.0 | 33.5 | 31.5 | 93.0 | 87.0 | Do. |
| 12.30 | 113.0 | 94.0 | 34.0 | 32.0 | 92.0 | 87.0 | Sun clear. |
| 12.35 | 120.5 | 100.0 | 35.0 | 33.0 | 94.0 | 89.0 | Do. |
| 12.40 | 124.0 | 102.0 | 36.5 | 34.0 | 93.0 | 88.0 | Sun in cloud. |
| 12.45 | 124.0 | 102.0 | 36.0 | 33.5 | 95.0 | 89.0 | Sun clear. |
| 12.50 | 130.0 | 105.0 | 37.5 | 34.5 | 97.0 | 90.0 | Do. |
| 12.55 | 132.0 | 106.0 | 38.0 | 35.0 | 96.0 | 90.5 | Do. |
| 1.00 | 135.0 | 108.0 | 39.0 | 35.5 | 98.5 | 91.0 | Do. |
| 1.05 | 138.0 | 110.0 | 40.0 | 36.0 | 101.0 | 92.0 | Sun in cloud. |
| 1.10 | 137.0 | 109.0 | 40.0 | 36.0 | 97.0 | 91.0 | Sun clear. |
| 1.15 | 139.0 | 110.5 | 40.0 | 36.0 | 98.0 | 91.5 | Do. |

The detailed observations show with sufficient completeness the conditions under which they were made. The best days upon which to undertake radiation observations are those which are perfectly cloudless, and, if possible, only such should be selected. But during the whole stay on Caroline Island there was no cloudless day, and consequently none of the observations were made under the best circumstances. However, on several days, there were intervals of several hours when the sky was clear, and results of some value can be obtained at such times. The clouds, moreover, which so continuously prevailed were of the cumulus type, and these have, at least approximately, the effect of a screen placed before the sun, concealing it for the time being, but allowing it to shine again with its former power when they have passed. The meteorological record shows that clouds of other varieties were rarely observed, though a haze was noted at times. The conjugate thermometers were very sensitive to a slight diminution in the sun's heat. It required only a very thin cloud to reduce the readings by many degrees, and it was some minutes after the passage of a cloud before the instruments rose to their proper temperature again. From fifteen minutes to half an hour should be allowed after the temporary concealment of the sun before the readings may be considered reliable, and a longer time may be necessary in the case of the VIOLLE bulbs, which are slower in their action on account of the time required for the bulbs of the thermometers within the spheres to be affected by changes in the temperature of their outer surfaces.

If we select from the observations those in which the sun was clear at the time, and had been for at least fifteen minutes previously, we shall find a sufficient number to warrant a more extended examination. It is possible to obtain from them an estimate of the solar intensity by several methods, and to institute a comparison between them. It is also possible to obtain a value of the solar constant. In the computation which follows the solar intensity is obtained by the methods available for the conjugate thermometers, VIOLLE's bulbs, and black and bright bulb thermometers, and a comparison made of the results, and in addition a value of the solar constant is determined from the observations with the conjugate thermometers.

*1. REDUCTION OF OBSERVATIONS MADE WITH THE CONJUGATE THERMOMETERS*

The bulletins of the Central Physical Observatory of Montsouris contain a general description of the instruments, but no rigid investigation of their theory. The differences between the readings of the black and bright thermometers are taken as a measure of the sun's intensity, and are used in the formula $T' - t = \theta p^{\varepsilon}$, in which $T'$, $t$ are the readings of the thermometers respectively, $\theta$ the solar constant, $p$ the diathermancy constant, and $\varepsilon$ the thickness of the layers of atmospheric air traversed by the solar rays. It is recognized, however, that the values of $\theta$ obtained by this formula are not the true solar constant, but vary with the instruments used,* having a value of 17° in the instruments used at Montsouris. For the purposes of comparison of the observations made from time to time, it is suggested that a conventional value of 100° be adopted for $\theta$, and that observations with different instruments be reduced to this standard by multiplying by a factor depending upon the value of $\theta$ for each instrument. At Montsouris, where $\theta = 17°$ for the pair of instruments described, the factor is $\frac{100}{17} = 5.88$, and the product of the observed differences $T' - t$ by this factor is called the "actinometric degree." In the case of observations made in 1873 and 1874 the differences $T' - t$ are published, but in observations since that time the actinometric degree is computed.

Quite recently a rigid investigation of the theory of these instruments has been made by Prof. WILLIAM FERREL, and is to be published in Professional Paper of the United States Signal Service No. XIII. It assumes the law of DULONG and PETIT, and derives formulæ for deducing the solar intensities and also the solar constant. Through the courtesy of the author, the formulæ have been furnished for this computation in advance of their publication. They are as follows:

"Let $\theta$ = the temperature of the black bulb.
$\theta_1$ = the temperature of the bright bulb.
$\theta'$ = the temperature of the inclosure (shade temp. approx.).
I = the intensity of solar radiation (calories per minute on square centimetre).
$\mu$ = constant 1.0077 ($\log \mu = \frac{1}{300}$).
$c$ = constant to be determined from observation.

We have then the following relations:

(1) .................. $\mathrm{I} = 4.584\,(\mu^{\theta} - \mu^{\theta'}) = 4.584\,\mu^{\theta'}\,(\mu^{\theta-\theta'} - 1)$

(2) .................. $\mathrm{I} = 4.584\,(\mu^{\theta} - \mu^{\theta_1})\,c = 4.584\,\mu^{\theta_1}\,(\mu^{\theta-\theta_1} - 1)c$

(3) .................. $\mu_{\theta'} = c\,\mu^{\theta_1} + (1 - c)\,\mu^{\theta}$."

From (1) the intensity is obtained from the readings of the black bulb in vacuo and the air temperature, which is approximately equal to that of the inclosure, or from (2) the intensity is obtained from the readings of the black and bright bulbs in vacuo, the constant $c$ being obtained from (3). The method assumes that $c$ can be obtained from observation, and thus the readings of the black and bright bulbs in vacuo be used in computing the solar intensities; $\theta$, $\theta_1$, and $\theta'$ are expressed in centigrade degrees.

* Bull. Mens. de l'Obs. Phys. Centr. de Montsouris, 1874, p. 189.

It first becomes necessary to compute the constant $c$. From (3) we have—

$$c = \frac{\mu^{\theta} - \mu^{\theta'}}{\mu^{\theta} - \mu^{\theta_1}}$$

In order to obtain the value of $c$ under varying conditions, observations were selected from different days and at different times of the day. The following table contains the observations used and the resulting values:

*Computation of c.*

| Date. | Time. | No. of obs. | $\theta$ | $\theta_1$ | $\theta'$ | c. |
|---|---|---|---|---|---|---|
| | | | ° | ° | ° | |
| April 27 | 9.00 a. m.; 12.15 p. m. | 2 | 58.9 | 43.1 | 29.7 | 1.79 |
| 28 | 9.35 a. m. to 2.08 p. m. | 10 | 61.4 | 45.7 | 30.3 | 1.87 |
| 30 | 3.00 p. m. to 5.00 p. m. | 5 | 52.9 | 39.6 | 28.8 | 1.74 |
| 30 | 7.00 a. m.; 5.00 p. m. | 2 | 44.8 | 34.6 | 28.2 | 1.59 |
| 30 | 9.00 a. m.; 3.00 p. m. | 2 | 58.5 | 42.9 | 29.7 | 1.74 |
| May 1 | 6.55 a. m. to 10.30 a. m. | 10 | 53.3 | 39.7 | 29.3 | 1.72 |
| 2 | 10.30 a. m. to 2.30 p. m. | 10 | 63.8 | 46.7 | 30.7 | 1.82 |
| 2 | 11.30 a. m. to 12.30 p. m. | 3 | 64.8 | 46.9 | 30.9 | 1.78 |
| 2 | 7.00 a. m.; 5.00 p. m. | 2 | 45.3 | 35.1 | 28.0 | 1.65 |
| 2 | 10.00 a. m.; 2.00 p. m. | 2 | 62.5 | 46.1 | 30.3 | 1.85 |
| 2 | 8.00 a. m.; 4.00 p. m. | 2 | 55.2 | 40.2 | 28.9 | 1.68 |

The resulting values of $c$ are quite discordant, and have a marked progression according to the values of $\theta$, or according to the hour of observation. They show that in the observations under discussion $c$ is not strictly a constant, but varies with the time of day. This may be true of the particular instruments used, or be due to some circumstance connected with the exposure of the instruments in these observations, or it may be inherent in this method of measuring solar radiation. Without further experiment it is impossible to discover the cause. It is therefore necessary to inquire what error is introduced by assuming a constant value of $c$. For his investigation the value $c = 1.75$ was assumed, and a computation of $\theta'$ made for observations on May 1 and 2. The following table gives the result of the computation and a comparison with the observed values of the same quantity:

*Comparison of computed with observed shade temperatures ($\theta'$).*

MAY 1.

| Time. | $\theta$. | $\theta$. | $\theta'$ obs. | $\theta'$ comp. | Obs. — comp. |
|---|---|---|---|---|---|
| A. M. | ° | ° | ° | ° | |
| 7.00 | 43.7 | 33.4 | 28.2 | 25.0 | + 3.2 |
| 7.30 | 50.2 | 37.3 | 28.6 | 26.7 | + 1.9 |
| 8.30 | 54.3 | 40.5 | 29.7 | 29.1 | + 0.6 |
| 9.00 | 57.2 | 42.2 | 29.8 | 29.7 | + 0.1 |
| 9.30 | 59.1 | 43.3 | 29.8 | 30.0 | — 0.2 |
| 10.00 | 60.6 | 44.6 | 30.0 | 31.1 | — 1.1 |
| 10.30 | 62.1 | 45.4 | 30.3 | 31.3 | — 1.0 |
| 11.00 | 63.6 | 46.3 | 29.9 | 31.6 | — 1.7 |
| 12.00 | 64.8 | 46.6 | 30.3 | 31.0 | — 0.7 |
| P. M. | | | | | |
| 1.00 | 63.5 | 46.6 | 30.4 | 32.2 | — 1.8 |
| 2.00 | 62.6 | 45.4 | 30.0 | 30.8 | — 0.8 |
| 3.00 | 58.8 | 43.3 | 29.5 | 30.3 | — 0.8 |
| 3.40 | 55.1 | 40.8 | 29.3 | 28.9 | + 0.4 |

MAY 2.

| | | | | | |
|---|---|---|---|---|---|
| A. M. | | | | | |
| 7.00 | 43.9 | 34.1 | 27.8 | 26.2 | + 1.6 |
| 7.10 | 49.9 | 37.0 | 28.5 | 26.1 | + 2.1 |
| 8.00 | 54.1 | 39.3 | 28.9 | 27.0 | + 1.9 |
| 8.30 | 52.4 | 39.3 | 29.1 | 28.5 | + 0.6 |
| 9.00 | 58.0 | 42.3 | 29.3 | 29.1 | + 0.2 |
| 10.00 | 62.2 | 45.5 | 30.0 | 31.4 | — 1.4 |
| 10.30 | 63.2 | 46.2 | 30.7 | 31.8 | — 1.1 |
| 11.00 | 64.2 | 46.7 | 30.6 | 31.8 | — 1.2 |
| 11.30 | 65.1 | 47.0 | 31.0 | 31.5 | — 0.5 |
| 12.00 | 64.7 | 46.8 | 31.0 | 31.5 | — 0.5 |
| P. M. | | | | | |
| 12.30 | 64.8 | 46.9 | 30.8 | 31.6 | — 0.8 |
| 1.00 | 64.6 | 47.2 | 30.6 | 32.4 | — 1.8 |
| 2.00 | 62.8 | 46.8 | 30.6 | 33.3 | — 2.7 |
| 2.30 | 60.8 | 45.8 | 30.4 | 33.3 | — 2.9 |
| 3.00 | 62.1 | 44.2 | 29.2 | 28.9 | + 0.3 |
| 3.30 | 58.5 | 42.4 | 29.2 | 28.8 | + 0.4 |
| 4.00 | 56.2 | 41.0 | 28.9 | 28.3 | + 0.6 |
| 4.30 | 52.1 | 38.7 | 28.4 | 27.6 | + 0.8 |
| 5.00 | 46.7 | 36.0 | 28.2 | 27.3 | + 0.9 |

This table shows the effect of using a constant value of $e$ between the hours of 7.00 a. m and 5.00 p. m. Had the value $e = 1.78$ been employed, the computed values would have been diminished by about 0°.5, and the mean of the residuals would have been nearly 0. There still would have remained, as was expected, plus residuals for the morning and evening observations, and minus residuals for those taken near the middle of the day. The magnitude of the residuals, while larger than was hoped for, is not sufficient to prevent the use of the method, but it renders advisable the computation of the solar intensities by equation (1) as well as equation (2). In the latter equation it was decided to use the value $e = 1.8$.

The following table contains the observations selected for the computation and the solar intensities obtained by equations (1) and (2). Those observations only were used in which the sun had been clear for some time before the observation. The mean of the corresponding readings with the two pairs of instruments was taken and the resulting values converted into centigrade degrees:

*Computation of solar intensities.*

[Conjugate thermometers.]

APRIL 28.

| Time. | $\theta$. | $\theta_1$. | $\theta'$. | $\theta - \theta_1$. | $\theta - \theta'$. | Intensity (1). $a$. from (2). | Intensity (1). $b$. from (1). | $a - b$. | Mean. |
|---|---|---|---|---|---|---|---|---|---|
| A. M. | | | | | | | | | |
| 9.00 | 59.0 | 42.2 | 29.0 | 16.8 | 30.0 | 1.570 | 1.483 | + 0.09 | 1.53 |
| 9.30 | 58.8 | 42.6 | 29.3 | 16.2 | 29.5 | 1.515 | 1.458 | + 0.06 | 1.49 |
| 9.35 | 59.4 | 43.1 | 29.3 | 16.3 | 30.1 | 1.530 | 1.491 | + 0.04 | 1.51 |
| 10.00 | 59.2 | 43.1 | 29.4 | 16.1 | 29.8 | 1.512 | 1.476 | + 0.04 | 1.49 |
| 10.35 | 59.9 | 43.9 | 29.9 | 16.0 | 30.0 | 1.509 | 1.493 | + 0.02 | 1.50 |
| 11.00 | 61.3 | 45.4 | 30.1 | 15.9 | 31.2 | 1.517 | 1.562 | — 0.04 | 1.54 |
| 11.30 | 60.9 | 45.6 | 30.4 | 15.3 | 30.5 | 1.459 | 1.527 | — 0.07 | 1.49 |
| 12.00 | 62.6 | 46.1 | 30.7 | 16.5 | 31.9 | 1.587 | 1.609 | — 0.02 | 1.60 |
| P. M. | | | | | | | | | |
| 12.30 | 64.5 | 47.9 | 31.0 | 16.6 | 33.5 | 1.619 | 1.705 | — 0.09 | 1.66 |
| 1.00 | 62.0 | 46.9 | 30.6 | 15.1 | 31.4 | 1.452 | 1.581 | — 0.13 | 1.52 |
| 1.30 | 60.7 | 46.6 | 30.6 | 14.1 | 30.1 | 1.348 | 1.506 | — 0.16 | 1.43 |

*Computation of solar intensities*—Continued.

APRIL 29.

| Time. | $\theta$. | $\theta_1$. | $\theta'$. | $\theta-\theta_1$. | $\theta-\theta'$. | Intensity (I). a. from (2). | Intensity (I). b. from (1). | a − b. | Mean. |
|---|---|---|---|---|---|---|---|---|---|
| A. M. | | | | | | | | | |
| 9.00 | 56.8 | 41.1 | 29.9 | 15.7 | 26.9 | 1.447 | 1.323 | + 0.12 | 1.38 |
| 10.00 | 61.9 | 44.7 | 30.6 | 17.2 | 31.3 | 1.640 | 1.574 | + 0.07 | 1.61 |
| 11.00 | 61.2 | 44.6 | 30.8 | 16.6 | 30.4 | 1.578 | 1.525 | + 0.05 | 1.55 |
| 11.15 | 62.4 | 45.7 | 30.9 | 16.7 | 31.5 | 1.603 | 1.589 | + 0.01 | 1.60 |
| 11.30 | 62.9 | 46.1 | 31.0 | 16.8 | 31.9 | 1.618 | 1.612 | + 0.01 | 1.62 |
| 11.45 | 63.1 | 46.3 | 30.7 | 16.8 | 32.4 | 1.620 | 1.638 | — 0.02 | 1.63 |
| 12.00 | 62.6 | 46.3 | 30.6 | 16.3 | 32.0 | 1.568 | 1.614 | 0.05 | 1.59 |
| P. M. | | | | | | | | | |
| 12.15 | 63.0 | 46.6 | 30.8 | 16.4 | 32.2 | 1.583 | 1.627 | — 0.04 | 1.60 |
| 12.30 | 63.1 | 46.9 | 31.1 | 16.2 | 32.0 | 1.566 | 1.621 | 0.06 | 1.59 |
| 1.30 | 60.4 | 46.2 | 30.9 | 14.2 | 29.5 | 1.353 | 1.476 | 0.12 | 1.41 |
| 2.10 | 59.4 | 45.9 | 30.9 | 13.5 | 28.5 | 1.281 | 1.421 | 0.14 | 1.35 |
| 2.30 | 58.9 | 45.6 | 30.8 | 13.3 | 28.1 | 1.257 | 1.398 | — 0.14 | 1.33 |
| 3.00 | 59.1 | 44.5 | 30.6 | 14.6 | 28.5 | 1.378 | 1.417 | — 0.14 | 1.40 |

APRIL 30.

| Time. | $\theta$. | $\theta_1$. | $\theta'$. | $\theta-\theta_1$. | $\theta-\theta'$. | a. | b. | a − b. | Mean. |
|---|---|---|---|---|---|---|---|---|---|
| A. M. | | | | | | | | | |
| 11.00 | 64.9 | 46.7 | 30.4 | 18.2 | 34.5 | 1.774 | 1.755 | + 0.02 | 1.76 |
| 11.30 | 64.9 | 47.4 | 30.5 | 17.5 | 34.4 | 1.706 | 1.751 | — 0.04 | 1.73 |
| 11.45 | 64.7 | 47.3 | 30.4 | 17.4 | 34.3 | 1.695 | 1.743 | — 0.05 | 1.72 |
| 12.00 | 64.9 | 47.7 | 30.4 | 17.2 | 34.5 | 1.678 | 1.755 | — 0.08 | 1.72 |
| P. M. | | | | | | | | | |
| 12.15 | 64.6 | 47.6 | 30.4 | 17.0 | 34.2 | 1.658 | 1.737 | — 0.08 | 1.70 |
| 3.00 | 58.4 | 43.0 | 29.3 | 15.4 | 29.1 | 1.439 | 1.436 | 0.00 | 1.44 |
| 3.30 | 56.4 | 41.7 | 29.2 | 14.7 | 27.2 | 1.357 | 1.332 | + 0.02 | 1.34 |
| 4.00 | 54.1 | 40.2 | 28.8 | 13.9 | 25.3 | 1.264 | 1.225 | + 0.04 | 1.24 |
| 4.30 | 50.2 | 37.9 | 28.4 | 12.3 | 21.8 | 1.093 | 1.039 | + 0.05 | 1.07 |
| 5.00 | 45.2 | 35.2 | 28.3 | 10.0 | 16.9 | 0.853 | 0.788 | + 0.06 | 0.82 |

MAY 1.

| Time. | $\theta$. | $\theta_1$. | $\theta'$. | $\theta-\theta_1$. | $\theta-\theta'$. | a. | b. | a − b. | Mean. |
|---|---|---|---|---|---|---|---|---|---|
| A. M. | | | | | | | | | |
| 6.45 | 39.8 | 31.1 | 28.0 | 8.7 | 11.8 | 0.723 | 0.538 | + 0.18 | 0.63 |
| 7.00 | 43.7 | 33.4 | 28.2 | 10.3 | 15.5 | 0.876 | 0.719 | + 0.16 | 0.80 |
| 7.15 | 46.6 | 35.1 | 28.4 | 11.5 | 18.2 | 0.996 | 0.855 | + 0.14 | 0.93 |
| 7.30 | 50.2 | 37.3 | 28.6 | 12.9 | 21.6 | 1.143 | 1.029 | + 0.11 | 1.09 |
| 8.30 | 54.3 | 40.5 | 29.7 | 13.8 | 24.6 | 1.258 | 1.196 | + 0.06 | 1.23 |
| 8.45 | 57.3 | 41.9 | 29.8 | 15.4 | 27.5 | 1.427 | 1.355 | + 0.07 | 1.39 |
| 9.00 | 57.2 | 42.2 | 29.8 | 15.0 | 27.4 | 1.392 | 1.348 | + 0.04 | 1.37 |
| 9.30 | 59.1 | 43.3 | 29.8 | 15.8 | 29.3 | 1.484 | 1.453 | + 0.03 | 1.47 |
| 10.00 | 60.6 | 44.6 | 30.0 | 16.0 | 30.6 | 1.517 | 1.528 | — 0.01 | 1.52 |
| 10.30 | 62.1 | 45.4 | 30.3 | 16.7 | 31.8 | 1.596 | 1.599 | 0.00 | 1.60 |
| 11.00 | 63.6 | 46.3 | 29.9 | 17.3 | 33.7 | 1.673 | 1.702 | — 0.03 | 1.69 |
| 12.00 | 64.8 | 46.6 | 30.3 | 18.2 | 34.5 | 1.770 | 1.753 | + 0.02 | 1.76 |
| P. M. | | | | | | | | | |
| 1.00 | 63.5 | 46.6 | 30.4 | 16.9 | 33.1 | 1.633 | 1.673 | — 0.04 | 1.65 |
| 2.00 | 62.6 | 45.4 | 30.0 | 17.2 | 32.6 | 1.649 | 1.641 | + 0.01 | 1.64 |
| 3.00 | 58.8 | 43.3 | 29.5 | 15.5 | 29.3 | 1.454 | 1.450 | 0.00 | 1.45 |
| 3.40 | 55.1 | 40.8 | 29.3 | 14.3 | 25.8 | 1.310 | 1.257 | + 0.05 | 1.28 |

*Computation of solar intensities*—Continued.

MAY 2.

| Time. | $\theta$ | $\theta_1$. | $\theta'$. | $\theta-\theta_1$. | $\theta-\theta'$. | Intensity (1). *a.* from (2). | Intensity (1). *b.* from (1). | $a-b$. | Mean. |
|---|---|---|---|---|---|---|---|---|---|
| A. M. | | | | | | | | | |
| 7.00 | 43.9 | 34.4 | 27.8 | 9.8 | 16.1 | 0.838 | 0.747 | + 0.09 | 0.79 |
| 7.40 | 49.9 | 37.0 | 28.5 | 12.9 | 21.4 | 1.141 | 1.018 | + 0.12 | 1.08 |
| 8.00 | 54.1 | 39.3 | 28.9 | 14.8 | 25.2 | 1.341 | 1.221 | + 0.12 | 1.28 |
| 8.30 | 52.4 | 39.3 | 29.1 | 13.1 | 23.3 | 1.181 | 1.123 | + 0.06 | 1.15 |
| 9.00 | 58.0 | 42.3 | 29.3 | 15.7 | 28.7 | 1.461 | 1.415 | + 0.05 | 1.44 |
| 10.00 | 62.2 | 45.5 | 30.0 | 16.7 | 32.2 | 1.601 | 1.617 | — 0.02 | 1.61 |
| 10.30 | 63.2 | 46.2 | 30.7 | 17.0 | 32.5 | 1.641 | 1.643 | 0.00 | 1.64 |
| 10.45 | 63.6 | 46.2 | 30.6 | 17.4 | 33.0 | 1.681 | 1.671 | + 0.01 | 1.68 |
| 11.00 | 64.2 | 46.7 | 30.6 | 17.5 | 33.6 | 1.697 | 1.706 | — 0.01 | 1.70 |
| 11.15 | 64.9 | 47.1 | 31.1 | 17.8 | 33.8 | 1.733 | 1.724 | + 0.01 | 1.73 |
| 11.30 | 65.1 | 47.0 | 31.0 | 18.1 | 34.1 | 1.763 | 1.740 | + 0.02 | 1.75 |
| 12.00 | 64.7 | 46.8 | 31.0 | 17.9 | 33.7 | 1.741 | 1.716 | + 0.02 | 1.73 |
| P. M. | | | | | | | | | |
| 12.30 | 64.8 | 46.9 | 30.8 | 17.9 | 34.0 | 1.743 | 1.731 | + 0.01 | 1.74 |
| 1.00 | 64.6 | 47.2 | 30.6 | 17.4 | 34.0 | 1.694 | 1.728 | — 0.03 | 1.71 |
| 2.00 | 62.8 | 46.8 | 30.6 | 16.0 | 32.2 | 1.542 | 1.625 | — 0.08 | 1.58 |
| 2.30 | 60.8 | 45.8 | 30.4 | 15.0 | 30.4 | 1.431 | 1.521 | — 0.09 | 1.48 |
| 3.00 | 62.1 | 44.2 | 29.2 | 17.9 | 32.9 | 1.707 | 1.648 | + 0.06 | 1.68 |
| 3.30 | 58.5 | 42.4 | 29.2 | 16.1 | 29.3 | 1.504 | 1.447 | + 0.06 | 1.48 |
| 4.00 | 56.2 | 41.0 | 28.9 | 15.2 | 27.3 | 1.400 | 1.334 | + 0.07 | 1.37 |
| 4.30 | 52.1 | 38.7 | 28.4 | 13.4 | 23.7 | 1.204 | 1.137 | + 0.07 | 1.17 |
| 4.45 | 49.1 | 37.2 | 28.3 | 11.9 | 20.8 | 1.051 | 0.985 | + 0.07 | 1.02 |
| 5.00 | 46.7 | 36.0 | 28.2 | 10.7 | 18.5 | 0.932 | 0.869 | + 0.06 | 0.90 |

MAY 3.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| A. M. | | | | | | | | | |
| 10.30 | 61.6 | 44.8 | 30.4 | 16.8 | 31.2 | 1.601 | 1.566 | + 0.04 | 1.58 |
| 11.00 | 64.3 | 46.4 | 30.8 | 17.9 | 33.5 | 1.736 | 1.703 | + 0.03 | 1.72 |
| 11.30 | 64.1 | 46.1 | 30.1 | 18.0 | 34.0 | 1.741 | 1.721 | + 0.02 | 1.73 |
| 12.00 | 64.3 | 46.4 | 30.5 | 17.9 | 33.8 | 1.736 | 1.716 | + 0.02 | 1.73 |
| P. M. | | | | | | | | | |
| 12.30 | 64.1 | 46.6 | 30.0 | 17.5 | 34.1 | 1.695 | 1.727 | — 0.03 | 1.71 |
| 1.00 | 63.9 | 46.8 | 30.4 | 17.1 | 33.5 | 1.658 | 1.697 | — 0.04 | 1.68 |
| 1.30 | 64.1 | 46.9 | 30.4 | 17.2 | 33.7 | 1.668 | 1.708 | — 0.04 | 1.69 |
| 2.00 | 62.7 | 45.9 | 30.3 | 16.8 | 32.4 | 1.615 | 1.633 | — 0.02 | 1.62 |
| 2.30 | 60.5 | 44.3 | 30.0 | 16.2 | 30.5 | 1.535 | 1.523 | + 0.01 | 1.53 |

MAY 5.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| A. M. | | | | | | | | | |
| 10.00 | 58.6 | 43.0 | 24.6 | 15.6 | 34.0 | 1.460 | 1.650 | — 0.19 | 1.56 |
| 10.30 | 61.4 | 44.7 | 25.6 | 16.7 | 35.8 | 1.591 | 1.764 | — 0.17 | 1.68 |
| 11.00 | 61.2 | 44.3 | 26.7 | 16.9 | 34.5 | 1.605 | 1.706 | — 0.10 | 1.66 |
| 11.30 | 61.2 | 44.6 | 27.2 | 16.6 | 34.0 | 1.578 | 1.683 | — 0.10 | 1.63 |

MAY 6.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| P. M. | | | | | | | | | |
| 1.15 | 59.4 | 43.5 | 29.4 | 15.9 | 30.0 | 1.495 | 1.487 | + 0.01 | 1.49 |
| 1.30 | 59.4 | 43.8 | 29.4 | 15.6 | 30.0 | 1.469 | 1.487 | — 0.02 | 1.48 |
| 2.00 | 57.6 | 43.4 | 29.4 | 14.2 | 28.2 | 1.325 | 1.388 | — 0.06 | 1.36 |
| 3.00 | 58.2 | 41.8 | 29.0 | 16.4 | 29.2 | 1.526 | 1.438 | + 0.09 | 1.48 |
| 3.15 | 56.9 | 40.9 | 29.0 | 16.0 | 27.9 | 1.474 | 1.367 | + 0.11 | 1.42 |

In the preceding table the sixth column contains the difference between the readings of the black bulb in vacuo ($\theta$) and the bright bulb in vacuo ($\theta_1$), and the seventh column the differences between the former and the shade temperatures ($\theta'$). The latter, which are given in the fifth column, have been obtained from the current meteorological record; they are the reading of the mercurial thermometer in the instrument shelter, reduced to centigrade measures. In a few cases the values were obtained by interpolation.

The column of differences ($a - b$) shows the discrepancies between the two methods. The signs are + for morning and evening values, and − for those in the middle of the day, as should be the case by taking a constant value of $e$. A comparison of the two methods shows no reason for preferring one to the other. The one which introduces the value of $e$—equation (2)—is open to the objection that it assumes a constant value for $e$ which it has been shown is only approximately true; it is possible that the deviations from constancy are due to the circumstances of these particular observations, and that consequently the intensities are not strictly accurate as computed. On the other hand, the method which uses the shade temperatures—equation (1)—is open to the uncertainties in the observations of that quantity, and assumes that these temperatures may be adopted as the temperatures of the inclosure of the black bulb thermometer. There seemed to be no reason for giving preference to either of the reductions. The last column contains the mean of the two series of values, which are adopted as the solar intensities given by the conjugate thermometers.

### 2. *REDUCTION OF OBSERVATIONS MADE WITH VIOLLE'S BULBS.*

The theory of these instruments is given by the inventor in his work upon solar radiation, above referred to, pp. 17–22 *. According to the method there explained, the intensities may be obtained by the equation:

$$q = K \frac{u\,u'}{u' - a\,u}$$

in which

$u$ = the difference between the reading of the thermometer in the blackened sphere and the air temperature.

$u'$ = the difference between the reading of the thermometer in the gilded sphere and the air temperature.

$a$ = the absorbing power of the gilded sphere in terms of that of the blackened sphere.

$K$ = a constant depending upon the instrument, and found by the methods explained.

If $K$ is undetermined, relative intensities can be obtained by the equation:

$$I = \frac{u\,u'}{u' - a\,u}$$

In this equation the quantities $u$ and $u'$ are obtained directly from the observations, but the constant $a$ must be derived experimentally. After the return of the expedition, a number of observations of this constant were made by screening the spheres and observing the rate of cooling of each, and also by observing the rate of increase of temperature when full sunlight was allowed to fall upon them after they had assumed the shade temperature behind the screen. The experiments gave the value $a = 0.5$, the large value being due to the tarnishing of the gilt, which was caused in part by the effect of the sea voyage. It is in part also apparently due to the poor manner in which the gilding has been done, as the same deterioration has been found in instruments which have never been used in actual work. Similar observations with a pair of instruments in which there was a good polish on the gilded sphere gave the value $a = 0.3$. It was decided to use the value 0.4 in the reduction as probably representing nearly the correct value for the condition of the gilt at Caroline Island. An approximate value is sufficient for determining the relative intensities, which is the aim of the present investigation.

The following table contains the computation for the same dates and times at which the readings of the conjugate thermometers were reduced. Other observations were reduced, but it is thought unnecessary to give the computation, as they show discordances due to the effect of passing clouds to a greater degree than those here given.

* See also *Annales de Chimie et de Physique*, 5e série, t. XVII, 1879.

*Computation of relative solar intensities.*

[VIOLLE'S bulbs.]

| Time. | Black. | Gilt. | Air. | *u*. | *u'*. | I. |
|---|---|---|---|---|---|---|
| **APRIL 28.** | | | | | | |
| A. M. | | | | | | |
| 9.00 | 40.8 | 36.4 | 29.4 | 11.4 | 7.0 | 33.2 |
| 9.30 | 41.1 | 36.6 | 29.3 | 11.8 | 7.3 | 33.1 |
| 9.35 | 41.8 | 37.2 | 29.3 | 12.5 | 7.9 | 34.1 |
| 10.00 | 41.0 | 36.3 | 29.4 | 11.6 | 6.9 | 34.8 |
| 10.35 | 43.0 | 38.2 | 29.9 | 13.1 | 8.3 | 35.1 |
| 11.00 | 43.8 | 38.7 | 30.1 | 13.7 | 8.6 | 38.0 |
| 11.30 | 43.4 | 38.6 | 30.4 | 13.0 | 8.2 | 35.5 |
| 12.00 | 44.4 | 39.2 | 30.7 | 13.7 | 8.5 | 38.8 |
| P. M. | | | | | | |
| 12.30 | 46.3 | 40.4 | 31.0 | 15.3 | 9.4 | 43.6 |
| 1.00 | 45.2 | 39.7 | 30.6 | 14.6 | 9.1 | 40.3 |
| 1.30 | 45.1 | 39.6 | 30.6 | 14.5 | 9.0 | 40.8 |
| **APRIL 29.** | | | | | | |
| A. M. | | | | | | |
| 9.00 | 39.7 | 36.0 | 29.9 | 9.8 | 6.1 | 27.2 |
| 10.00 | 43.1 | 38.9 | 30.6 | 12.5 | 8.3 | 31.4 |
| 11.00 | 45.6 | 38.2 | 30.8 | 14.8 | 7.4 | 73.0 |
| 11.15 | 45.6 | 38.7 | 30.9 | 14.7 | 7.8 | 60.3 |
| 11.30 | 45.6 | 39.9 | 31.0 | 14.6 | 8.9 | 41.9 |
| 11.45 | 45.6 | 39.5 | 30.7 | 14.9 | 8.8 | 46.8 |
| 12.00 | 45.5 | 39.9 | 30.6 | 14.9 | 9.3 | 42.0 |
| P. M. | | | | | | |
| 12.15 | 45.5 | 39.8 | 30.8 | 14.7 | 9.0 | 42.7 |
| 12.30 | 45.5 | 40.2 | 31.1 | 14.4 | 9.1 | 39.7 |
| 1.30 | 46.0 | 39.5 | 30.9 | 15.1 | 8.6 | 49.9 |
| 2.10 | 46.0 | 39.7 | 30.9 | 15.1 | 8.8 | 47.5 |
| 2.30 | 46.0 | 39.7 | 30.8 | 15.2 | 8.9 | 48.3 |
| 3.00 | 46.0 | 39.2 | 30.6 | 15.4 | 8.6 | 55.2 |
| **APRIL 30.** | | | | | | |
| A. M. | | | | | | |
| 11.00 | 46.7 | 42.6 | 30.4 | 16.3 | 12.2 | 34.9 |
| 11.30 | 46.2 | 41.8 | 30.5 | 15.7 | 11.3 | 35.5 |
| 11.45 | 45.4 | 40.8 | 30.4 | 15.0 | 10.4 | 35.5 |
| 12.00 | 46.5 | 41.9 | 30.4 | 16.1 | 11.5 | 36.3 |
| P. M. | | | | | | |
| 12.15 | 45.5 | 40.5 | 30.4 | 15.1 | 10.1 | 37.2 |
| 3.00 | 41.7 | 37.4 | 29.3 | 12.4 | 8.1 | 32.4 |
| 3.30 | 39.8 | 35.5 | 29.2 | 10.6 | 6.3 | 31.8 |
| 4.00 | 39.5 | 35.9 | 28.8 | 10.7 | 7.1 | 27.1 |
| 4.30 | 36.7 | 34.2 | 28.4 | 8.3 | 5.8 | 19.3 |
| 5.00 | 35.2 | 32.4 | 28.3 | 6.9 | 4.1 | 21.8 |
| **MAY 1.** | | | | | | |
| A. M. | | | | | | |
| 7.00 | 33.5 | 31.3 | 28.2 | 5.3 | 3.1 | 16.4 |
| 7.15 | 34.4 | 32.0 | 28.4 | 6.0 | 3.6 | 18.0 |
| 7.30 | 37.5 | 34.1 | 28.6 | 8.9 | 5.5 | 25.8 |
| 8.30 | 40.8 | 36.5 | 29.7 | 11.1 | 6.8 | 31.4 |
| 8.45 | 41.8 | 37.5 | 29.8 | 12.0 | 7.7 | 31.9 |
| 9.00 | 42.6 | 38.4 | 29.8 | 12.8 | 8.6 | 31.4 |
| 9.30 | 44.0 | 39.6 | 29.8 | 14.2 | 9.8 | 33.9 |
| 10.00 | 44.6 | 40.0 | 30.0 | 14.6 | 10.0 | 34.8 |
| 10.30 | 44.8 | 39.9 | 30.3 | 14.5 | 9.6 | 36.6 |
| 11.00 | 46.9 | 41.8 | 29.9 | 17.0 | 11.9 | 39.7 |
| 12.00 | 47.2 | 41.6 | 30.3 | 16.9 | 11.3 | 42.4 |
| P. M. | | | | | | |
| 1.00 | 46.7 | 41.3 | 30.4 | 16.3 | 10.9 | 40.4 |
| 2.00 | 46.2 | 40.7 | 30.0 | 16.2 | 10.7 | 41.3 |
| 3.00 | 45.4 | 40.3 | 29.5 | 15.9 | 10.8 | 39.0 |
| 3.40 | 43.0 | 38.7 | 29.3 | 13.7 | 9.4 | 33.0 |

*Computation of relative solar intensities*—Continued.

MAY 2.

| Time. | Black. | Gilt. | Air. | *u*. | *u′*. | I. |
|---|---|---|---|---|---|---|
| A. M. | | | | | | |
| 7.00 | 32.9 | 30.8 | 27.8 | 5.1 | 3.0 | 15.3 |
| 7.40 | 38.0 | 34.9 | 28.5 | 9.5 | 6.4 | 23.4 |
| 8.00 | 40.3 | 36.5 | 28.9 | 11.4 | 7.6 | 28.9 |
| 8.30 | 39.8 | 36.5 | 29.1 | 10.7 | 7.4 | 25.5 |
| 9.00 | 42.0 | 38.0 | 29.3 | 12.7 | 8.7 | 30.7 |
| 10.00 | 45.6 | 40.5 | 30.0 | 15.6 | 10.5 | 38.4 |
| 10.30 | 45.5 | 40.8 | 30.7 | 14.8 | 10.1 | 35.6 |
| 10.45 | 45.9 | 41.0 | 30.6 | 15.3 | 10.4 | 37.0 |
| 11.00 | 46.3 | 41.3 | 30.6 | 15.7 | 10.7 | 38.2 |
| 11.15 | 47.0 | 41.7 | 31.1 | 15.9 | 10.6 | 40.4 |
| 11.30 | 46.9 | 41.7 | 31.0 | 15.9 | 10.7 | 39.6 |
| 12.00 | 46.2 | 41.1 | 31.0 | 15.2 | 10.1 | 38.4 |
| P. M. | | | | | | |
| 12.30 | 46.0 | 41.6 | 30.8 | 15.2 | 10.8 | 34.9 |
| 1.00 | 47.9 | 42.6 | 30.6 | 17.3 | 12.0 | 40.7 |
| 2.00 | 49.1 | 43.6 | 30.6 | 18.5 | 13.0 | 42.9 |
| 2.30 | 47.8 | 42.7 | 30.4 | 17.4 | 12.3 | 40.4 |
| 3.00 | 47.5 | 42.4 | 29.2 | 18.3 | 13.2 | 40.9 |
| 3.30 | 44.8 | 40.4 | 29.2 | 15.6 | 11.2 | 34.9 |
| 4.00 | 43.9 | 39.6 | 28.9 | 15.0 | 10.7 | 34.1 |
| 4.30 | 40.0 | 36.8 | 28.4 | 11.6 | 8.4 | 25.6 |
| 4.45 | 37.0 | 34.1 | 28.3 | 8.7 | 5.8 | 21.9 |
| 5.00 | 35.9 | 33.3 | 28.2 | 7.7 | 5.1 | 19.6 |

MAY 3.

| Time. | Black. | Gilt. | Air. | *u*. | *u′*. | I. |
|---|---|---|---|---|---|---|
| A. M. | | | | | | |
| 10.30 | 43.6 | 38.7 | 30.4 | 13.2 | 8.3 | 36.5 |
| 11.00 | 44.2 | 39.2 | 30.8 | 13.4 | 8.4 | 37.5 |
| 11.30 | 44.5 | 39.5 | 30.1 | 14.4 | 9.4 | 37.6 |
| 12.00 | 44.9 | 39.8 | 30.5 | 14.4 | 9.3 | 38.3 |
| P. M. | | | | | | |
| 12.30 | 45.2 | 40.0 | 30.0 | 15.2 | 10.0 | 39.0 |
| 1.00 | 45.9 | 40.5 | 30.4 | 15.5 | 10.1 | 40.1 |
| 1.30 | 46.2 | 41.0 | 30.4 | 15.8 | 10.6 | 38.9 |
| 2.00 | 44.8 | 39.8 | 30.3 | 14.5 | 9.5 | 37.2 |
| 2.30 | 43.9 | 39.1 | 30.0 | 13.9 | 9.1 | 36.1 |

MAY 5.

| Time. | Black. | Gilt. | Air. | *u*. | *u′*. | I. |
|---|---|---|---|---|---|---|
| A. M. | | | | | | |
| 10.00 | 39.7 | 35.7 | 24.6 | 15.1 | 11.1 | 32.9 |
| 10.30 | 41.7 | 37.2 | 25.6 | 16.1 | 11.6 | 35.9 |
| 11.00 | 40.8 | 36.3 | 26.7 | 14.1 | 9.6 | 33.8 |
| 11.30 | 41.4 | 36.7 | 27.2 | 14.2 | 9.5 | 35.5 |

MAY 6.

| Time. | Black. | Gilt. | Air. | *u*. | *u′*. | I. |
|---|---|---|---|---|---|---|
| P. M. | | | | | | |
| 1.15 | 39.7 | 36.0 | 29.4 | 10.3 | 6.6 | 27.2 |
| 1.30 | 39.8 | 36.1 | 29.4 | 10.4 | 6.7 | 27.9 |
| 2.00 | 39.7 | 36.0 | 29.4 | 10.3 | 6.6 | 27.2 |
| 3.00 | 39.5 | 35.8 | 29.0 | 10.5 | 6.8 | 27.5 |
| 3.15 | 38.6 | 35.3 | 29.0 | 9.6 | 6.3 | 24.2 |

It is evident from an examination of the values in the last column that observations were often made when the instruments had not recovered from the effect of passing clouds. This is especially true on April 29, which is here given as an illustration of the effect of frequent clouds upon the indications of the instruments. This sluggishness seems to be greater than that of the conjugate thermometers. Further remarks on this point are given below in the section devoted to a comparison of the results of the different computations.

### 3. *REDUCTION OF OBSERVATIONS MADE WITH THE BLACK AND BRIGHT THERMOMETERS EXPOSED IN FULL SUNLIGHT, BUT NOT IN VACUO.*

The same formula used for the reduction of observations with VIOLLE's bulbs serves for the computation of solar intensities from readings of black and bright bulb thermometers not in vacuo. The absorption constant $a$ is, however, different. In the computation, the results of which are given in the following table, the value $a = \frac{1}{6}$ is adopted as representing the theoretical value of the radiating power of the bright bulb in terms of that of the black bulb:

*Computation of relative solar intensities.*

[Black and bright bulbs not in vacuo.]

APRIL 28.

| Time. | 1137. | 1136. | Air. | $a$. | $a'$. | I. |
|---|---|---|---|---|---|---|
| A. M. | | | | | | |
| 9.00 | 36.3 | 32.9 | 29.4 | 6.9 | 3.5 | 10.5 |
| 9.30 | 38.1 | 33.3 | 29.3 | 8.8 | 4.0 | 14.1 |
| 9.35 | 37.8 | 33.3 | 29.3 | 8.5 | 4.0 | 13.1 |
| 10.00 | 38.2 | 33.0 | 29.4 | 8.8 | 3.6 | 15.1 |
| 10.35 | 39.1 | 34.6 | 29.9 | 9.2 | 4.7 | 13.5 |
| 11.00 | 39.2 | 34.6 | 30.1 | 9.1 | 4.5 | 13.6 |
| 11.30 | 38.3 | 34.4 | 30.4 | 7.9 | 4.0 | 11.7 |
| 12.00 | 40.6 | 35.7 | 30.7 | 9.9 | 5.0 | 14.6 |
| P. M. | | | | | | |
| 12.30 | 41.4 | 36.4 | 31.0 | 10.4 | 5.4 | 15.2 |
| 1.00 | 40.0 | 36.0 | 30.6 | 9.4 | 5.4 | 13.4 |
| 1.30 | 39.6 | 35.6 | 30.6 | 9.0 | 5.0 | 12.9 |

APRIL 30.

| Time. | 1137. | 1136. | Air. | $a$. | $a'$. | I. |
|---|---|---|---|---|---|---|
| A. M. | | | | | | |
| 11.00 | 42.8 | 37.2 | 30.4 | 12.4 | 6.8 | 17.9 |
| 11.30 | 40.8 | 36.7 | 30.5 | 10.3 | 6.2 | 14.2 |
| 11.45 | 42.9 | 37.5 | 30.4 | 12.5 | 7.1 | 17.8 |
| 12.00 | 43.3 | 38.1 | 30.4 | 12.9 | 7.7 | 18.1 |
| P. M. | | | | | | |
| 12.15 | 43.0 | 37.7 | 30.4 | 12.6 | 7.3 | 17.7 |
| 3.00 | 36.9 | 33.9 | 29.3 | 7.6 | 4.6 | 10.6 |
| 3.30 | 36.8 | 33.1 | 29.2 | 7.6 | 3.9 | 11.4 |
| 4.00 | 36.4 | 32.5 | 28.8 | 7.6 | 3.7 | 11.7 |
| 4.30 | 34.2 | 30.8 | 28.4 | 5.8 | 2.4 | 9.9 |

MAY 1.

| Time. | 1137. | 1136. | Air. | $a$. | $a'$. | I. |
|---|---|---|---|---|---|---|
| A. M. | | | | | | |
| 7.00 | 31.8 | 29.2 | 28.2 | 3.6 | 1.0 | 9.0 |
| 7.15 | 32.5 | 29.6 | 28.4 | 4.1 | 1.2 | 9.8 |
| 7.30 | 33.4 | 30.6 | 28.6 | 4.8 | 2.0 | 8.0 |
| 8.30 | 36.7 | 33.3 | 29.7 | 7.0 | 3.6 | 10.5 |
| 8.45 | 36.8 | 32.9 | 29.8 | 7.0 | 3.1 | 11.4 |
| 9.00 | 37.5 | 33.6 | 29.8 | 7.7 | 3.8 | 11.7 |
| 9.30 | 38.4 | 34.4 | 29.8 | 8.6 | 4.6 | 12.4 |
| 10.00 | 39.4 | 35.0 | 30.0 | 9.4 | 5.0 | 13.8 |
| 10.30 | 39.7 | 35.6 | 30.3 | 9.4 | 5.3 | 13.5 |
| 11.00 | 41.4 | 37.3 | 29.9 | 11.5 | 7.4 | 15.5 |
| 12.00 | 41.4 | 37.4 | 30.3 | 11.1 | 7.1 | 14.9 |
| P. M. | | | | | | |
| 1.00 | 41.9 | 37.3 | 30.4 | 11.5 | 6.9 | 15.9 |
| 2.00 | 41.2 | 36.1 | 30.0 | 11.2 | 6.1 | 16.3 |
| 3.00 | 39.2 | 35.0 | 29.5 | 9.7 | 5.5 | 13.7 |
| 3.40 | 37.5 | 33.6 | 29.3 | 8.2 | 4.3 | 12.2 |

*Computation of relative solar intensities*—Continued.

MAY 2.

| Time. | 1137. | 1136. | Air. | *a.* | *b.* | I. |
|---|---|---|---|---|---|---|
| A. M. | | | | | | |
| 7.00 | 30.7 | 28.9 | 27.8 | 2.9 | 1.1 | 5.3 |
| 7.40 | 32.9 | 30.6 | 28.5 | 4.4 | 2.1 | 6.6 |
| 8.00 | 34.7 | 31.7 | 28.9 | 5.8 | 2.8 | 9.0 |
| 8.30 | 36.8 | 32.8 | 29.1 | 7.7 | 3.7 | 11.9 |
| 9.00 | 38.3 | 33.6 | 29.3 | 9.0 | 4.3 | 13.8 |
| 10.00 | 40.4 | 35.6 | 30.0 | 10.4 | 5.6 | 14.9 |
| 10.30 | 39.4 | 35.4 | 30.7 | 8.7 | 4.7 | 12.4 |
| 10.45 | 40.8 | 35.8 | 30.6 | 10.2 | 5.2 | 15.2 |
| 11.00 | 41.1 | 36.1 | 30.6 | 10.5 | 5.5 | 15.6 |
| 11.15 | 42.1 | 36.9 | 31.1 | 11.0 | 5.8 | 16.0 |
| 11.30 | 42.9 | 36.9 | 31.0 | 11.9 | 5.9 | 18.0 |
| 12.00 | 41.1 | 36.5 | 31.0 | 10.1 | 5.5 | 14.6 |
| P. M. | | | | | | |
| 12.30 | 41.8 | 36.9 | 30.8 | 11.0 | 6.1 | 15.6 |
| 1.00 | 42.8 | 36.9 | 30.6 | 12.2 | 6.3 | 17.9 |
| 2.00 | 41.8 | 37.1 | 30.6 | 11.2 | 6.5 | 15.8 |
| 2.30 | 40.3 | 36.4 | 30.4 | 9.9 | 6.0 | 13.5 |
| 3.00 | 40.1 | 35.3 | 29.2 | 10.9 | 6.1 | 15.5 |
| 3.30 | 39.3 | 34.4 | 29.2 | 10.1 | 5.2 | 15.0 |
| 4.00 | 38.3 | 33.6 | 28.9 | 9.4 | 4.7 | 14.2 |
| 4.30 | 36.3 | 31.4 | 28.4 | 7.9 | 3.0 | 14.0 |
| 4.45 | 33.9 | 30.6 | 28.3 | 5.6 | 2.3 | 9.2 |
| 5.00 | 33.1 | 30.3 | 28.2 | 4.9 | 2.1 | 7.9 |

MAY 3.

| Time. | 1137. | 1136. | Air. | *a.* | *b.* | I. |
|---|---|---|---|---|---|---|
| A. M. | | | | | | |
| 10.30 | 40.0 | 35.6 | 30.4 | 9.6 | 5.2 | 13.9 |
| 11.00 | 40.0 | 35.7 | 30.8 | 9.2 | 4.9 | 13.3 |
| 11.30 | 40.8 | 36.1 | 30.1 | 10.7 | 6.0 | 15.3 |
| 12.00 | 40.8 | 36.4 | 30.5 | 10.3 | 5.9 | 14.5 |
| P. M. | | | | | | |
| 12.30 | 41.1 | 36.7 | 30.0 | 11.1 | 6.7 | 15.6 |
| 1.00 | 41.8 | 36.7 | 30.4 | 11.4 | 6.3 | 16.3 |
| 1.30 | 41.4 | 37.1 | 30.4 | 11.0 | 6.7 | 15.0 |
| 2.00 | 41.1 | 36.2 | 30.3 | 10.8 | 5.9 | 15.5 |
| 2.30 | 39.4 | 35.6 | 30.0 | 9.4 | 5.6 | 13.2 |

MAY 6.

| Time. | 1137. | 1136. | Air. | *a.* | *b.* | I. |
|---|---|---|---|---|---|---|
| P. M. | | | | | | |
| 1.15 | 36.7 | 33.1 | 29.4 | 7.3 | 3.7 | 10.8 |
| 1.30 | 37.1 | 33.2 | 29.1 | 7.7 | 3.8 | 11.7 |
| 2.00 | 36.8 | 33.1 | 29.4 | 7.4 | 3.7 | 11.0 |
| 3.00 | 36.2 | 32.9 | 29.0 | 7.2 | 3.9 | 10.4 |
| 3.15 | 35.4 | 32.2 | 29.0 | 6.4 | 3.2 | 9.8 |

An examination of the values of the intensity given in the last column shows many irregularities. This is not due to the effect of passing clouds, as in the former methods, for the thermometers recover quickly their former condition after the clouds have passed, but to changes in the velocity of the wind. The method is confessedly approximate, since the least increase in the force of the wind which blows on the bulbs, or the least decrease, changes the effect of convection and so produces discordancies in the observations. The values obtained are therefore more of interest for comparison than for their intrinsic merit.

4. *COMPARISON OF THE RELATIVE INTENSITIES*

It remains to make a comparison between the intensities obtained by the three methods in use. For this purpose they must be reduced to a common scale. The intensity at 12.00 on May 1 has been taken as 1, and the intensities at other times divided by the intensities given by each method at the chosen time. In the first two methods the relative values are less than 1, because the intensities at 12.00 on May 1 are the highest observed (with one or two exceptions); but in the last method there are values greater than 1, because this is not the case. The relatively small value at 12.00 on May 1 seems to be due to accidental conditions.

The following table contains the relative intensities by the three methods:

*Comparison of relative intensities by the three methods.*

APRIL 28.

| Time. | Conj. therms. | VIOLLE'S bulbs. | Ordinary therms. |
|---|---|---|---|
| A. M. | | | |
| 9.00 | 0.86 | 0.78 | 0.70 |
| 9.30 | 0.85 | 0.78 | 0.95 |
| 9.35 | 0.86 | 0.80 | 0.88 |
| 10.00 | 0.85 | 0.82 | 1.01 |
| 10.30 | 0.85 | 0.88 | 0.83 |
| 10.35 | 0.85 | 0.83 | 0.91 |
| 11.00 | 0.87 | 0.90 | 0.91 |
| 11.30 | 0.85 | 0.84 | 0.79 |
| 12.00 | 0.91 | 0.92 | 0.98 |
| P. M. | | | |
| 12.30 | 0.94 | 1.03 | 1.02 |
| 1.00 | 0.86 | 0.95 | 0.90 |
| 1.30 | 0.81 | 0.96 | 0.87 |

APRIL 30.

| Time. | Conj. therms. | VIOLLE'S bulbs. | Ordinary therms. |
|---|---|---|---|
| A. M. | | | |
| 11.00 | 1.00 | 0.82 | 1.20 |
| 11.30 | 0.98 | 0.84 | 0.95 |
| 11.45 | 0.98 | 0.84 | 1.19 |
| 12.00 | 0.98 | 0.86 | 1.21 |
| P. M. | | | |
| 12.15 | 0.97 | 0.88 | 1.19 |
| 3.00 | 0.82 | 0.76 | 0.71 |
| 3.30 | 0.76 | 0.75 | 0.77 |
| 4.00 | 0.70 | 0.64 | 0.79 |
| 4.30 | 0.61 | 0.46 | 0.66 |
| 5.00 | 0.47 | 0.51 | .... |

MAY 1.

| Time. | Conj. therms. | VIOLLE'S bulbs. | Ordinary therms. |
|---|---|---|---|
| A. M. | | | |
| 7.00 | 0.45 | 0.39 | 0.60 |
| 7.15 | 0.53 | 0.42 | 0.66 |
| 7.30 | 0.62 | 0.61 | 0.54 |
| 8.30 | 0.70 | 0.74 | 0.70 |
| 8.45 | 0.79 | 0.75 | 0.77 |
| 9.00 | 0.78 | 0.74 | 0.79 |
| 9.30 | 0.84 | 0.80 | 0.83 |
| 10.00 | 0.86 | 0.82 | 0.93 |
| 10.30 | 0.91 | 0.86 | 0.91 |
| 11.00 | 0.96 | 0.94 | 1.04 |
| 12.00 | 1.00 | 1.00 | 1.00 |
| P. M. | | | |
| 1.00 | 0.94 | 0.95 | 1.07 |
| 2.00 | 0.93 | 0.97 | 1.09 |
| 3.00 | 0.82 | 0.92 | 0.92 |
| 3.40 | 0.73 | 0.78 | 0.82 |

*Comparison of relative intensities by the three methods*—Continued.

MAY 2.

| Time. | Conj. therms. | VIOLLE'S bulbs. | Ordinary therms. |
|---|---|---|---|
| A. M. | | | |
| 7.00 | 0.45 | 0.36 | 0.36 |
| 7.10 | 0.61 | 0.55 | 0.44 |
| 8.00 | 0.73 | 0.68 | 0.60 |
| 8.30 | 0.65 | 0.60 | 0.80 |
| 9.00 | 0.82 | 0.72 | 0.93 |
| 10.00 | 0.91 | 0.90 | 1.00 |
| 10.30 | 0.93 | 0.84 | 0.83 |
| 10.45 | 0.95 | 0.87 | 1.02 |
| 11.00 | 0.97 | 0.90 | 1.05 |
| 11.15 | 0.98 | 0.95 | 1.07 |
| 11.30 | 0.99 | 0.93 | 1.21 |
| 12.00 | 0.98 | 0.91 | 0.98 |
| P. M. | | | |
| 12.30 | 0.99 | 0.82 | 1.05 |
| 1.00 | 0.97 | 0.96 | 1.20 |
| 2.00 | 0.90 | 1.01 | 1.06 |
| 2.30 | 0.84 | 0.95 | 0.91 |
| 3.00 | 0.95 | 0.96 | 1.04 |
| 3.30 | 0.84 | 0.82 | 1.01 |
| 4.00 | 0.78 | 0.80 | 0.95 |
| 4.30 | 0.66 | 0.60 | 0.94 |
| 4.45 | 0.58 | 0.52 | 0.62 |
| 5.00 | 0.51 | 0.46 | 0.53 |

MAY 3.

| Time. | Conj. therms. | VIOLLE'S bulbs. | Ordinary therms. |
|---|---|---|---|
| A. M. | | | |
| 10.30 | 0.90 | 0.86 | 0.93 |
| 11.00 | 0.98 | 0.88 | 0.89 |
| 11.30 | 0.98 | 0.89 | 1.03 |
| 12.00 | 0.98 | 0.90 | 0.97 |
| P. M. | | | |
| 12.30 | 0.97 | 0.92 | 1.05 |
| 1.00 | 0.95 | 0.95 | 1.09 |
| 1.30 | 0.96 | 0.92 | 1.01 |
| 2.00 | 0.92 | 0.88 | 1.04 |
| 2.30 | 0.87 | 0.85 | 0.89 |

MAY 6.

| Time. | Conj. therms. | VIOLLE'S bulbs. | Ordinary therms. |
|---|---|---|---|
| P. M. | | | |
| 1.15 | 0.85 | 0.69 | 0.72 |
| 1.30 | 0.84 | 0.66 | 0.79 |
| 2.00 | 0.77 | 0.64 | 0.74 |
| 3.00 | 0.84 | 0.65 | 0.70 |
| 3.15 | 0.81 | 0.57 | 0.66 |

The above table shows plainly the effect of temporary influences in modifying the observed intensities, and also that the different instruments are differently affected by the same influences. In order to eliminate the accidental peculiarities and obtain a more reliable comparison of the methods the following table has been computed. It combines the observations made at the same hour on the different days, and uses those times only at which observations on two or more days were made.

*Mean relative intensities observed at the same hour on two or more days by the three methods.*

| Hour. | Conj. therms. | VIOLLE's bulbs. | Ordinary therms. |
|---|---|---|---|
| A. M. | | | |
| 7.00 | 0.45 | 0.38 | 0.48 |
| 8.30 | 0.68 | 0.67 | 0.75 |
| 9.00 | 0.82 | 0.75 | 0.81 |
| 9.30 | 0.84 | 0.79 | 0.89 |
| 10.00 | 0.87 | 0.85 | 0.98 |
| 10.30 | 0.90 | 0.86 | 0.88 |
| 11.00 | 0.96 | 0.89 | 1.02 |
| 11.30 | 0.95 | 0.88 | 1.00 |
| 12.00 | 0.97 | 0.92 | 1.03 |
| P. M. | | | |
| 12.30 | 0.97 | 0.92 | 1.04 |
| 1.00 | 0.93 | 0.95 | 1.06 |
| 1.30 | 0.88 | 0.94 | 0.94 |
| 2.00 | 0.92 | 0.95 | 1.06 |
| 2.30 | 0.86 | 0.90 | 0.90 |
| 3.00 | 0.86 | 0.88 | 0.89 |
| 3.30 | 0.80 | 0.78 | 0.89 |
| 4.00 | 0.74 | 0.72 | 0.87 |
| 4.30 | 0.64 | 0.53 | 0.80 |

The accompanying chart represents graphically the values given in the above table. The full curve corresponds to the intensities given by the conjugate thermometers, the dotted curve to those given by VIOLLE's bulbs, the broken curve to those given by the ordinary black and bright thermometers. The original values by which the curves were drawn are represented by ⊙, ·, and +, respectively.

### 5. SUMMARY OF RESULTS.

The discussion given in the preceding pages has given us values of the solar intensities on the days of observation by three different methods. It has thus furnished incidentally a means of comparison of the methods, in so far as the observations themselves allow this to be done. The uncertainties arising from the state of the sky have already been mentioned; their effect is shown in the discordances which the results at different hours on the same day exhibit. By including favorable times only, the tables showing the relative intensities by the different methods represent fairly the results obtained under the best conditions during the series of observations. The following summary gives the conclusions derived from an examination of the results:

1. The method of the black and bright bulb thermometers freely exposed in the air gives only an approximate determination of the solar intensity. This was expected, and is due to the constantly varying conditions of exposure, caused by the effect of the winds on convection currents.

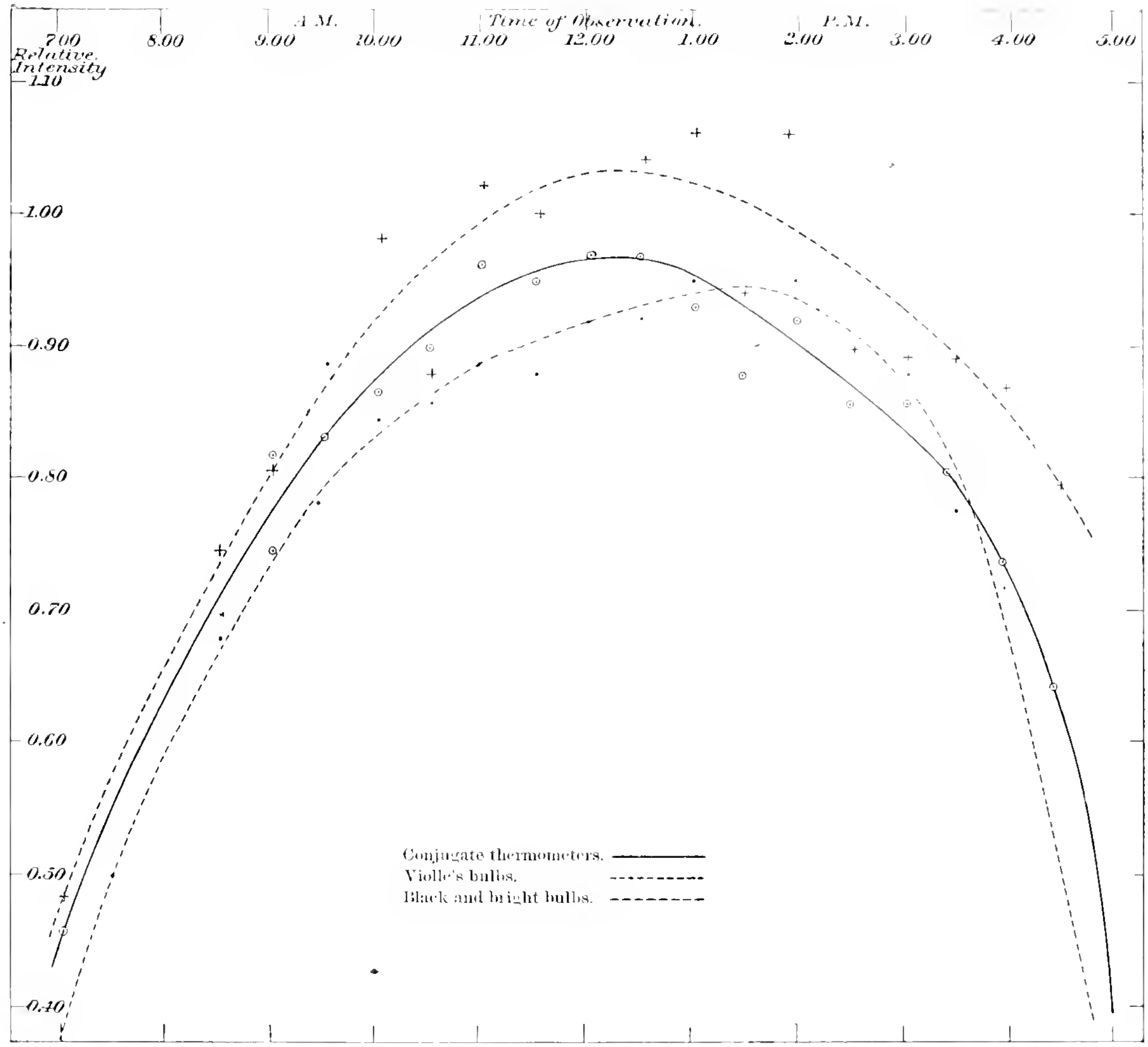
2. VIOLLE's bulbs are affected by convection, but the effect is shown less than in freely exposed thermometers, on account of the position of the thermometers within. The observations on the afternoon of May 2, when the air was almost perfectly still, show higher intensities than the corresponding times on other days, but the observations are not sufficient to indicate how much the results are influenced by this cause.

3. The intensities by the conjugate thermometers seem also to be affected by the varying influence of convection, but in this case (and in the preceding also) direct experiments would give more information as to this effect than any examination of these observations.

4. The intensities by VIOLLE's bulbs (see the curves) are smaller in the morning and greater in the afternoon than those by the conjugate thermometers. There is a marked difference

**Fig. 13.**

CHART OF RELATIVE INTENSITIES.



in the times of the maximum readings, the VIOLLE bulbs reaching the maximum one hour later than the conjugate thermometers. This shows that the former are sluggish in their action, and at any given time show the intensity not for that time but for a time already past by many minutes. The sluggishness of the VIOLLE bulbs was also indicated by the long time which was required after the passage of a cloud before their return to a normal condition.

5. The curve corresponding to the intensities given by the conjugate thermometers represents the relative solar intensities as accurately as the observations permit for the period April 28 to May 3. It is impossible to give any mathematical estimate of the uncertainty of the numerical values which would be obtained from this curve. It is probable that the values are liable to an uncertainty of several hundredths, but not as great as a tenth. They may be accepted as the final values of the relative solar intensity obtained at Caroline Island. Expressed in terms of the 12.00 value they are as follows:

*Relative solar intensity at Caroline Island, April 28 to May 3, 1883.*

| Time. | Intensity. | Time. | Intensity. | Time. | Intensity. |
|---|---|---|---|---|---|
| A. M. | | A. M. | | P. M. | |
| 7.00 | 0.47 | 10.30 | 0.94 | 2.00 | 0.93 |
| 7.30 | 0.57 | 11.00 | 0.97 | 2.30 | 0.90 |
| 8.00 | 0.66 | 11.30 | 0.99 | 3.00 | 0.87 |
| 8.30 | 0.73 | 12.00 | 1.00 | 3.30 | 0.82 |
| 9.00 | 0.80 | P. M. | | 4.00 | 0.76 |
| 9.30 | 0.87 | 12.30 | 1.00 | 4.30 | 0.66 |
| 10.00 | 0.91 | 1.00 | 0.98 | 5.00 | 0.46 |
| | | 1.30 | 0.96 | | |

6. *DETERMINATION OF THE SOLAR CONSTANT.*

The investigation upon the theory of the conjugate thermometers made by Prof. WILLIAM FERREL (Professional Papers of the U. S. Signal Service, No. XIII) contains formulæ for the derivation of the solar constant from the solar intensities given by the observations. Adopting his notation, and referring to the Professional Paper itself for an explanation of the method of deriving the formulæ, we have the following:

Let $A$ = the solar constant,*

$p$ = the diathermancy constant,

$I$ = the solar intensity at any given hour of the day,

$A_1, p_1\ I_1$ = assumed values of the above,

$\delta A,\ \delta p_1\ \delta I$ = the corrections to the assumed values.

Then—

(1) . . . . . . . . . . . . . . . . . . $A = A_1 + \delta A$

(2) . . . . . . . . . . . . . . . . . . $p = p_1 + \delta p$

(3) . . . . . . . . . . . . . . . . . . $I = I_1 + \delta I$

Let $\varepsilon$ = the thickness of the atmosphere through which the sun's rays pass ($\varepsilon = 1$ when sun is in zenith). Then—

(4) . . . . . . . . . . . $I_1 = A_1 \left( p_1^{\epsilon} + 0.025 \frac{\varepsilon(\varepsilon-1)}{2} p_1^{\epsilon-2} \right)$

(5) . . . . . . . . . . . $\delta I = p_1^{\epsilon}\, \delta A + A_1\, \varepsilon\, p_1^{(\epsilon-1)}\, \delta p$

* The solar constant in Professor FERREL's investigation is the amount of heat received on a square centimetre of surface at the upper limits of the atmosphere, expressed in calories. The calorie is the amount of heat necessary to raise the temperature of one gramme of water 1° centigrade. By these definitions the constant = 2 ± a decimal.

If $p$ is not constant during the day then $\delta p + t\,\delta' p$ must be substituted for $\delta p$ in the last equation.

In § 1 there have been given values of the solar intensities obtained from the readings of the conjugate thermometers. These, after the rejection of a few discordant observations, were used in the above formulæ for deriving values of $A$ and $p$. The first step in the computation consisted in the computation of the values of $\varepsilon$ for different hours of the day by means of the well-known formulæ—

$$\varepsilon = \sec z \qquad \cos z = \sin \varphi \sin \delta + \cos \varphi \cos \delta \cos h$$

in which—

$z$ = sun's zenith distance,
$\delta$ = sun's declination,
$h$ = sun's hour angle,
$\varphi$ = latitude of the station.

A table was computed from which the values of $\varepsilon$ were obtained for each observation.

Approximate values of $A$ and $p$ were then obtained by trial computations with equation (4), using a few of the observations on each day. The following were adopted:

| | $A$. | $p$. |
|---|---|---|
| April 28 | 1.96 | 0.859 |
| 29 | 2.18 | 0.760 |
| 30 | 2.27 | 0.776 |
| May 1 | 3.02 | 0.614 |
| 2 | 2.20 | 0.805 |
| 3 | 2.20 | 0.805 |

With these values, equation (4) was used to give computed values of $I$, for comparison with the observed values. The resulting residuals were used in equation (5) to give the corrections $\delta A$ and $\delta p$ by the method of least squares. It was found by the computation that the observations on April 28 were discordant, and also were not of sufficient range to give successful results since they extend from 9.00 a. m. to 1.30 only. Observations taken at early or late hours are necessary to give sufficiently large values of $\varepsilon$ for the computation. It was also found that the assumed values of $A$ and $p$ on April 30, May 1, 2, 3 were not near enough to reduce the residuals satisfactorily. Consequently a second approximation was made for these dates, using the values of $A$ and $p$ derived from the first computation for the dates April 30 and May 2, but deriving new trial-values for May 1 and 3. The coefficients $p_1^{\varepsilon}$ and $A_1, \varepsilon\, p_1^{(\varepsilon-1)}$ were recomputed on the second approximation for greater accuracy. The labor involved in these computations was very great; the results obtained are given in the following tables:

TABLE I.—*Values of A and p at each approximation.*

| | $A$. | | | $p$. | | |
|---|---|---|---|---|---|---|
| | 1st approx. | Assumed for 2d approx. | 2d approx. | 1st approx. | Assumed for 2d approx. | 2d approx. |
| April 29 | 2.194 | - - - - - | - - - - - | 0.734 | - - - - - | - - - - - |
| 30 | 2.358 | 2.358 | 2.337 | 0.745 | 0.745 | 0.751 |
| May 1 | 1.983 | 2.25 | 2.327 | 0.756 | 0.756 | 0.737 |
| 2 | 2.315 | 2.315 | 2.303 | 0.760 | 0.760 | 0.764 |
| 3 | 2.611 | 2.40 | 2.576 | 0.665 | 0.730 | 0.690 |

TABLE II.—*Comparison of computed and observed solar intensities.*

APRIL 29.

| Time. | Intensities. Observed. | Computed. I. | Computed. II. | Computed. III. | Residuals (obs. — comp.) I. | Residuals (obs. — comp.) II. | Residuals (obs. — comp.) III. |
|---|---|---|---|---|---|---|---|
| A. M. | | | | | | | |
| 9.00 | 1.38 | 1.45 | 1.38 | - - - | — 0.07 | 0.00 | - - - - |
| 10.00 | 1.61 | 1.55 | 1.50 | - - - | + .06 | + .11 | - - - - |
| 11.00 | 1.55 | 1.60 | 1.55 | - - - | — .05 | .00 | - - - - |
| 11.15 | 1.60 | 1.61 | 1.56 | - - - | — .01 | + .04 | - - - - |
| 11.30 | 1.62 | 1.62 | 1.57 | - - - | .00 | + .05 | - - - - |
| 11.45 | 1.63 | 1.62 | 1.57 | - - - | + .01 | + .06 | - - - - |
| 12.00 | 1.59 | 1.62 | 1.57 | - - - | — .03 | + .02 | - - - - |
| P. M. | | | | | | | |
| 12.15 | 1.60 | 1.62 | 1.57 | - - - | — .02 | + .03 | - - - - |
| 12.30 | 1.59 | 1.61 | 1.56 | - - - | — .02 | + .03 | - - - - |
| 1.30 | 1.41 | 1.58 | 1.52 | - - - | — .17 | — .11 | - - - - |
| 2.10 | 1.35 | 1.53 | 1.47 | - - - | — .18 | — .12 | - - - - |
| 2.30 | 1.33 | 1.50 | 1.44 | - - - | — .17 | — .11 | - - - - |
| 3.00 | 1.40 | 1.43 | 1.37 | - - - | — .03 | + .03 | - - - - |

APRIL 30.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| A. M. | | | | | | | |
| 11.00 | 1.76 | 1.71 | 1.69 | 1.69 | + 0.05 | + 0.07 | + 0.07 |
| 11.30 | 1.73 | 1.72 | 1.70 | 1.71 | + .01 | + .03 | + .02 |
| 11.45 | 1.72 | 1.72 | 1.71 | 1.71 | .00 | + .01 | + .01 |
| 12.00 | 1.72 | 1.72 | 1.71 | 1.71 | .00 | + .01 | + .01 |
| P. M. | | | | | | | |
| 12.15 | 1.70 | 1.72 | 1.71 | 1.71 | — .02 | — .01 | — .01 |
| 3.00 | 1.44 | 1.54 | 1.50 | 1.50 | — .10 | — .06 | — .06 |
| 3.30 | 1.34 | 1.45 | 1.40 | 1.41 | — .11 | — .06 | — .07 |
| 4.00 | 1.24 | 1.33 | 1.26 | 1.27 | — .09 | — .02 | — .03 |
| 4.30 | 1.07 | 1.15 | 1.02 | 1.07 | — .08 | + .05 | .00 |
| 5.00 | 0.82 | 0.88 | 0.75 | 0.78 | — .06 | + .07 | + .04 |

MAY 1.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| A. M. | | | | | | | |
| 7.00 | 0.80 | 0.48 | 0.74 | 0.77 | + 0.32 | + 0.06 | + 0.03 |
| 7.15 | 0.93 | 0.67 | 0.87 | 0.93 | + .26 | + .06 | .00 |
| 7.30 | 1.09 | 0.83 | 0.97 | 1.05 | + .26 | + .12 | + .04 |
| *8.30 | 1.23 | 1.29 | 1.23 | - - - | — .06 | .00 | - - - - |
| 8.45 | 1.39 | 1.38 | 1.27 | 1.42 | + .01 | + .12 | — .03 |
| *9.00 | 1.37 | 1.44 | 1.31 | - - - | — .07 | + .06 | - - - - |
| 9.30 | 1.47 | 1.56 | 1.36 | 1.54 | — .09 | + .11 | — .07 |
| 10.00 | 1.52 | 1.64 | 1.40 | 1.59 | — .12 | + .12 | — .07 |
| 10.30 | 1.60 | 1.70 | 1.43 | 1.62 | — .10 | + .17 | — .02 |
| 11.00 | 1.69 | 1.74 | 1.45 | 1.65 | — .05 | + .24 | + .04 |
| 12.00 | 1.76 | 1.77 | 1.47 | 1.67 | — .01 | + .29 | + .09 |
| P. M. | | | | | | | |
| 1.00 | 1.65 | 1.73 | 1.44 | 1.64 | — .08 | + .21 | + .01 |
| 2.00 | 1.64 | 1.63 | 1.40 | 1.58 | + .01 | + .24 | + .06 |

* Rejected on second approximation.

TABLE II.—*Comparison of computed and observed solar intensities*—Continued.

MAY 2.

| Time. | Intensities. Observed. | Computed. I. | Computed. II. | Computed. III. | Residuals (obs.—comp.) I. | Residuals (obs.—comp.) II. | Residuals (obs.—comp.) III. |
|---|---|---|---|---|---|---|---|
| A. M. | | | | | | | |
| 7.00 | 0.79 | 1.06 | 0.88 | 0.89 | — 0.27 | — 0.09 | — 0.10 |
| 7.40 | 1.08 | 1.33 | 1.21 | 1.22 | — .25 | — .13 | — .14 |
| 8.00 | 1.28 | 1.42 | 1.32 | 1.32 | — .11 | — .04 | — .04 |
| 10.00 | 1.61 | 1.68 | 1.64 | 1.64 | — .07 | — .03 | — .03 |
| 10.30 | 1.64 | 1.71 | 1.68 | 1.68 | — .07 | — .04 | — .04 |
| 10.45 | 1.68 | 1.72 | 1.69 | 1.69 | — .04 | — .01 | — .01 |
| 11.00 | 1.70 | 1.72 | 1.70 | 1.70 | — .02 | .00 | .00 |
| 11.15 | 1.73 | 1.73 | 1.71 | 1.71 | .00 | + .02 | + .02 |
| 11.30 | 1.75 | 1.73 | 1.71 | 1.71 | + .02 | + .04 | + .04 |
| 12.00 | 1.73 | 1.74 | 1.72 | 1.72 | — .01 | + .01 | + .01 |
| P. M. | | | | | | | |
| 12.30 | 1.74 | 1.73 | 1.71 | 1.71 | + .01 | + .03 | + .03 |
| 1.00 | 1.71 | 1.72 | 1.70 | 1.70 | — .01 | + .01 | + .01 |
| 2.00 | 1.58 | 1.67 | 1.63 | 1.64 | — 09 | — .05 | — .06 |
| 2.30 | 1.48 | 1.63 | 1.59 | 1.59 | — .15 | — .13 | — .11 |
| 3.00 | 1.68 | 1.58 | 1.52 | 1.52 | + .10 | + .16 | + .16 |
| 3.30 | 1.48 | 1.50 | 1.42 | 1.42 | — .02 | + .06 | + .06 |
| 4.00 | 1.37 | 1.40 | 1.29 | 1.30 | — .03 | + .08 | + .07 |
| 4.30 | 1.17 | 1.24 | 1.09 | 1.10 | — .07 | + .08 | + .07 |
| 5.00 | 0.90 | 1.00 | 0.80 | 0.82 | — .10 | + .10 | + .08 |

MAY 3.

| Time. | Observed. | Computed. I. | Computed. II. | Computed. III. | Residuals I. | Residuals II. | Residuals III. |
|---|---|---|---|---|---|---|---|
| A. M. | | | | | | | |
| 10.30 | 1.58 | 1.70 | 1.61 | 1.66 | — 0.12 | — 0.03 | — 0.08 |
| 11.00 | 1.72 | 1.72 | 1.64 | 1.69 | .00 | + .08 | + .03 |
| 11.30 | 1.73 | 1.73 | 1.66 | 1.71 | .00 | + .07 | + .02 |
| 12.00 | 1.73 | 1.73 | 1.67 | 1.71 | .00 | + .06 | + .02 |
| P. M. | | | | | | | |
| 12.30 | 1.71 | 1.73 | 1.66 | 1.71 | — .02 | + .05 | .00 |
| 1.00 | 1.68 | 1.72 | 1.64 | 1.68 | — .04 | + .04 | .00 |
| 1.30 | 1.69 | 1.70 | 1.60 | 1.65 | — .01 | + .09 | + .04 |
| 2.00 | 1.62 | 1.67 | 1.55 | 1.61 | — .05 | + .07 | + .01 |
| 2.30 | 1.53 | 1.63 | 1.18 | 1.54 | — .10 | + .05 | — .01 |

In the above table the columns I, II, III of intensities and residuals refer to the first computation, with the assumed values of $A$ and $p$, the result of the first approximation, and the result of the second approximation respectively. An examination of the last column of residuals shows how nearly the second approximation represents the original observations. There are a few large residuals, but on the whole the agreement is very satisfactory.

The resulting values of the solar constant have been given in Table I, and show excellent agreement. Collecting them here, with the interval of time covered by the observations on each day, we have the following results:

SOLAR CONSTANT.

| Date. | Interval. | $A$. |
|---|---|---|
| April 29 | 9.00 a. m. to 3.00 p. m. | 2.194 |
| 30 | 11.00 a. m. to 5.00 p. m. | 2.337 |
| May 1 | 7.00 a. m. to 2.00 p. m. | 2.327 |
| 2 | 7.00 a. m. to 5.00 p. m. | 2.303 |
| 3 | 10.30 a. m. to 2.30 p. m. | 2.576 |

Mean of all, 2.347.
Mean of April 30 to May 2, 2.322.

The corresponding values of $p$ are 0.735 and 0.751, respectively. Early morning and evening observations are wanting on April 29 and May 3, and when this is the case values of $A$ between 2.2 and 2.6 will satisfy the observations with nearly equal accuracy. It seemed best, therefore, to adopt for the final value that obtained on the dates April 30, May 1 and 2, viz:

$$A = 2.322$$

Reducing to the sun's mean distance we have finally:

$$A = 2.285$$

### *RADIATION OBSERVATIONS DURING THE ECLIPSE.*

There has already been given a detailed account of the observations of solar radiation made from day to day, and the methods of reduction by which values of the solar intensity were obtained. On the day of the eclipse, readings were made from 10.00 a. m. to 1.15 p. m. by Seaman J. C. HAROLD, of the *Hartford*. They were made every two minutes from 11.30 to 11.40, in which interval the period of totality was included, and every five minutes at other times. Flying clouds concealed the sun at occasional intervals, and thereby affected the observations to some extent, but the results are quite satisfactory. The instruments used were conjugate thermometers Nos. 1 and 3, VIOLLE'S bulbs with black-bulb thermometers Nos. 742 and 751, and ordinary black and bright bulb thermometers Nos. 1137 and 1136. The observer made readings to the nearest half degree. The observations in detail are given in connection with those of other days.

The design of the observations was to determine what proportion of heat received by the earth was cut off by the concealing of the sun, and also the shape of the curve representing the varying solar intensity. The necessary computations were made on the plan already fully explained. The following table contains the results of the computation; the air temperatures were interpolated from the curve previously given.

*Solar intensities during eclipse.*

| Time. | Intensities. Conjugate thermometers. *a.* | *b.* | Mean. | VIOLLE'S bulbs. | Relative intensities. Conj. therms. | VIOLLE'S bulbs. |
|---|---|---|---|---|---|---|
| A. M. | | | | | | |
| 10.00 | 1.625 | 1.469 | 1.55 | 26.1 | 0.88 | 0.62 |
| 10.05 | 1.658 | 1.498 | 1.58 | 29.2 | 0.90 | 0.69 |
| 10.10 | 1.653 | 1.505 | 1.58 | 29.7 | 0.90 | 0.70 |
| 10.15 | 1.603 | 1.472 | 1.54 | 26.4 | 0.88 | 0.62 |
| 10.20 | 1.543 | 1.439 | 1.49 | 26.4 | 0.85 | 0.62 |
| 10.25 | 1.522 | 1.407 | 1.46 | 22.5 | 0.83 | 0.53 |
| 10.30 | 1.436 | 1.332 | 1.38 | 22.2 | 0.78 | 0.52 |
| 10.35 | 1.343 | 1.260 | 1.30 | 19.4 | 0.74 | 0.46 |
| 10.40 | 1.144 | 1.059 | 1.10 | 15.9 | 0.62 | 0.38 |
| 10.45 | 0.837 | 0.768 | 0.80 | 8.5 | 0.45 | 0.20 |
| 10.50 | 0.887 | 0.821 | 0.85 | 11.6 | 0.48 | 0.27 |
| 10.55 | 0.867 | 0.816 | 0.84 | 14.6 | 0.48 | 0.34 |
| 11.00 | 0.811 | 0.766 | 0.79 | 11.9 | 0.45 | 0.28 |
| 11.05 | 0.716 | 0.662 | 0.69 | 8.6 | 0.39 | 0.20 |
| 11.10 | 0.587 | 0.546 | 0.57 | - - - - | 0.32 | - - - - |
| 11.15 | 0.465 | 0.431 | 0.45 | - - - - | 0.26 | - - - - |
| 11.20 | 0.568 | 0.421 | 0.49 | - - - - | 0.28 | - - - - |
| 11.25 | 0.224 | 0.182 | 0.20 | - - - - | 0.11 | - - - - |
| 11.30 | 0.135 | 0.092 | 0.11 | - - - - | 0.06 | - - - - |
| 11.32 | 0.125 | 0.067 | 0.10 | - - - - | 0.06 | - - - - |

*Solar intensities during eclipse*—Continued.

| Time. | Intensities. | | | | Relative intensities. | |
|---|---|---|---|---|---|---|
| | Conjugate thermometers. | | | VIOLLE'S bulbs. | Conj. therms. | VIOLLE'S bulbs. |
| | *a.* | *b.* | Mean. | | | |
| A. M. | | | | | | |
| 11.34 | 0.087 | 0.049 | 0.07 | - - - - | 0.04 | - - - - |
| 11.36 | - - - - | - - - - | - - - - | - - - - | - - - - | - - - - |
| 11.38 | - - - - | - - - - | - - - - | - - - - | - - - - | - - - - |
| 11.40 | - - - - | - - - - | - - - - | - - - - | - - - - | - - - - |
| 11.45 | - - - - | - - - - | - - - - | - - - - | - - - - | - - - - |
| 11.50 | 0.087 | 0.049 | 0.07 | - - - - | 0.04 | - - - - |
| 11.55 | 0.174 | 0.142 | 0.16 | - - - - | 0.09 | - - - - |
| 12.00 | 0.224 | 0.190 | 0.21 | - - - - | 0.12 | - - - - |
| P. M. | | | | | | |
| 12.05 | 0.316 | 0.264 | 0.29 | - - - - | 0.16 | - - - - |
| 12.10 | 0.453 | 0.411 | 0.43 | - - - - | 0.24 | - - - - |
| 12.15 | 0.506 | 0.459 | 0.48 | 7.6 | 0.27 | 0.18 |
| 12.20 | 0.412 | 0.375 | 0.39 | 5.0 | 0.22 | 0.12 |
| 12.25 | 0.716 | 0.657 | 0.69 | 15.8 | 0.39 | 0.37 |
| 12.30 | 0.910 | 0.761 | 0.84 | 14.6 | 0.48 | 0.34 |
| 12.35 | 1.008 | 0.969 | 0.99 | 18.8 | 0.56 | 0.44 |
| 12.40 | 1.093 | 1.083 | 1.08 | 18.5 | 0.61 | 0.44 |
| 12.45 | 1.093 | 1.054 | 1.07 | 14.3 | 0.61 | 0.34 |
| 12.50 | 1.259 | 1.228 | 1.24 | 22.7 | 0.70 | 0.54 |
| 12.55 | 1.330 | 1.288 | 1.31 | 22.2 | 0.74 | 0.52 |
| 1.00 | 1.392 | 1.371 | 1.38 | 26.1 | 0.78 | 0.62 |
| 1.05 | 1.463 | 1.459 | 1.46 | 29.2 | 0.83 | 0.69 |
| 1.10 | 1.449 | 1.426 | 1.14 | 29.2 | 0.82 | 0.69 |
| 1.15 | 1.487 | 1.487 | 1.49 | 29.2 | 0.85 | 0.69 |

In the preceding table no intensities are given for the VIOLLE bulbs between 11.10 a. m and 12.10 p. m., because the fraction $\frac{uu'}{u'-au}$ becomes indeterminate in this interval. The reduction of the observations with the black and bright bulbs freely exposed is not given, because of their approximate character. The former are, however, used in drawing the curve previously given under the head "black bulb thermometer."

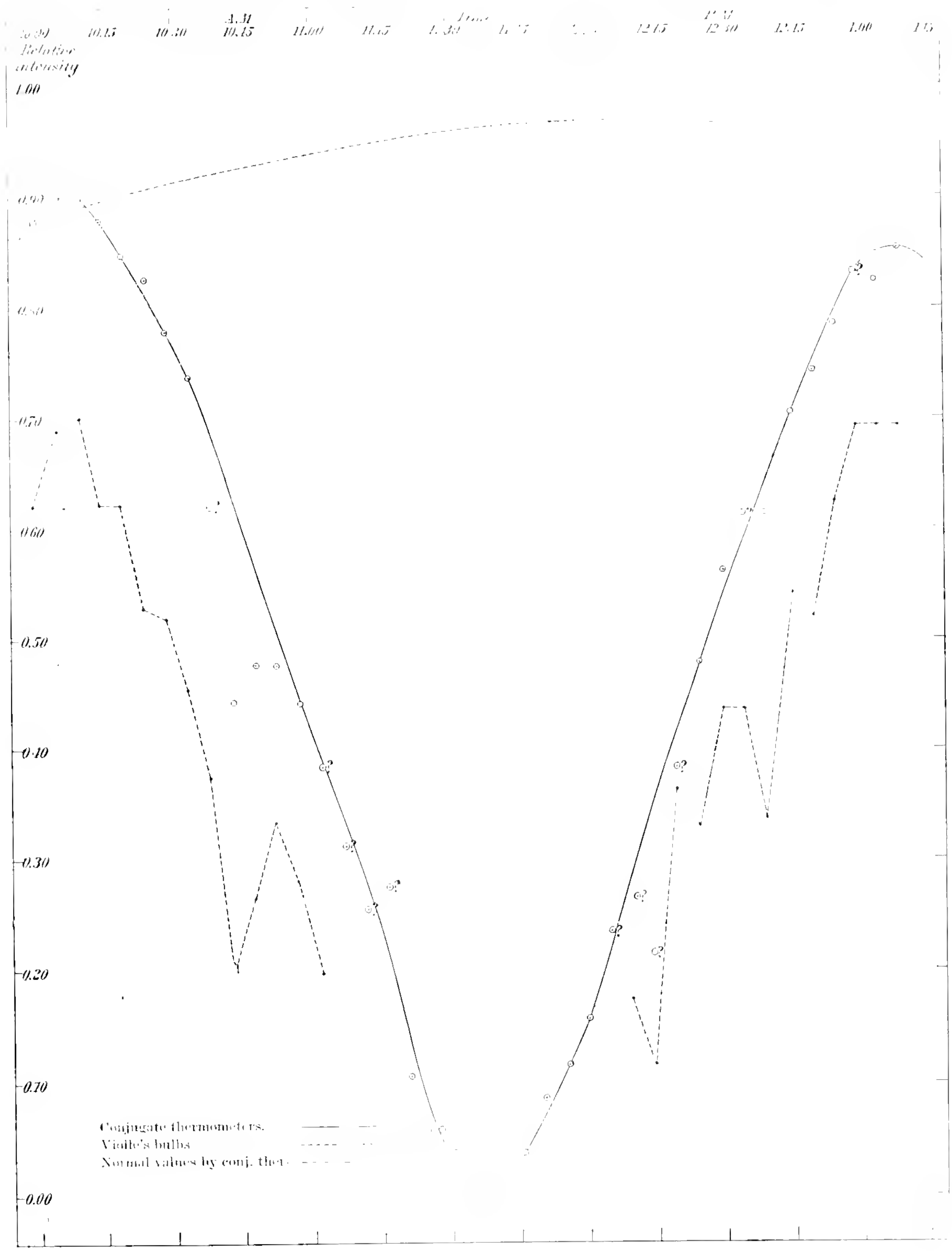
The relative intensities are expressed in the same unit used in reducing all the radiation observations, viz, the intensity in each series at 12.00 May 1 adopted as 1. In order to express graphically the observations, the following chart is given. In it the relative intensities obtained with the conjugate thermometers are represented by ⊙ and the curve drawn through them. A query, ?, at the side of the observation indicates that the sun was in a cloud at the time, which has been taken account of in drawing the curve. The dotted line is used to connect the observations with the VIOLLE bulbs, but no curve is drawn, since it is evident that its position would be quite conjectural, on account of the slow recovery of the instruments from the effects of the passing clouds. The broken curve at the top of the chart shows the usual form of the curve of intensity given by the conjugate thermometers, reproduced here for the sake of comparison.

An examination of the observations and the results of the computation leads to the following conclusions:

1. The readings of all the instruments were essentially the same at the close of totality, and agreed with the observed air temperature. This indicates that during the total phase no heat was received by the earth from the atmosphere, as far as these instruments allowed its measurement. It need hardly be said that the radiation instruments are not intended to show the effect

Fig. 14.

CHART OF RELATIVE INTENSITIES OF SOLAR RADIATION DURING ECLIPSE.



of the heat of the corona, and are not sensitive enough for such refined measurement. Their use is to measure the effect of heat which is received from the sun and by reflection from the atmosphere—the heat which is a factor in causing vegetable growth; they do not claim a position as delicate physical instruments. The observations show that during the eclipse the amount of heat gradually diminished until practically none was received, and the temperature of night was attained.

2. The maximum point of the curve in the first partial phase is at about 10.08 a. m., or four minutes after the first contact. This four minutes covers whatever tardiness the instruments possess, as well as the natural increase of solar heat in the morning, until it was overbalanced by the direct cutting off of a portion of the sun's heat. The minimum point of the curve is at about 11.40 a. m., or three minutes after the observed time of third contact. This time is somewhat uncertain, as from the nature of the case this portion of the curve is drawn arbitrarily, the intensities having become indeterminate. The second maximum is at 1.15 p. m., four minutes after the last contact was noted. The afternoon observations do not indicate as great intensities as the morning, as is further indicated by the computed diathermancy constants given below. The sky was observed to be quite hazy as the day advanced.

3. A measure of the clearness of the atmosphere can be obtained by computing the constant $p$ in equation (4), using for $A$ the value 2.322, and for $I$ the intensities computed from the observations. This computation has been made for the two observations at 10.00 and 10.05 a. m. at the beginning of the eclipse, and for those at 1.15 and 1.30 p. m., after its close. The following are the results:

| Time. | $p$. | Mean. |
|---|---|---|
| 10.00 a. m. | 0.727 | 0.732 |
| 10.05 a. m. | 0.737 | |
| 1.15 p. m. | 0.687 | 0.688 |
| 1.30 p. m. | 0.690 | |

The mean value of $p$ corresponding with the adopted value of $A$ is 0.751. It is seen, then, that at the beginning of the eclipse the clearness of the sky was about normal, or slightly below the normal, but that after the eclipse it was decidedly below the average value. The computation, therefore, confirms the evidence given by the intensities on May 6 compared with other days, and also the ocular evidence, that during the eclipse the sky was not wholly clear, but that there was a perceptible haziness.

## § 5. BOTANY OF CAROLINE ISLAND.

(Collections by Dr. DIXON and identifications by Dr. WILLIAM TRELEASE, of the University of Wisconsin.)

Dr. DIXON made a complete collection of botanical specimens from the south island, and included in his examination all the portions of the whole group visited by him. This collection was turned over by me to Professor TRELEASE for examination, and I have to express the thanks of the expedition to him for his very satisfactory report, which follows.

The collection was in a very poor state for examination, and must have presented great difficulties. I would call attention to the fact that out of 28 specimens collected a great number (21) are, I believe, not included in the report of the WILKES exploring expedition.

Mr. UPTON also made a collection, which, however, arrived in such a condition as not to allow of accurate discussion. Dr. DIXON'S memorandum accompanying his collection, is as follows:

"The vegetation of these coral islets is luxuriant, and in some portions quite dense, yet the variety of species does not cover a wide range.

"The botanical specimens gathered comprise the entire flora of the islet occupied by the United States Eclipse Expedition, excepting two varieties of portulaca, the cocoa-nut palm, pine apple, papaw, and pandanus. Of the trees, there being several varieties, there were procured leaves, old and young bark, and flower and fruit where possible.

"The smaller plants yielded stems, root, and the flower, etc., when present.

"Two varieties of grass were also obtained.

"The pandanus, portulacæ, cocoa nut, fig, papaw, and pumpkin were recognized.

"A large tree, forty or fifty feet in height, with a trunk four feet in diameter, is probably the Pisonia grandis.

"The wood of a small tree, No. 7 (in collection), is capable of a high polish. Some of the specimens may deteriorate and become unrecognizable, but the limited means for preservation at hand were fully made use of. Large roots and fruit are preserved in a box, numbers corresponding to appropriate specimens between bibulous papers, being affixed."

The report of Professor TRELEASE is given below:

UNIVERSITY OF WISCONSIN, BOTANICAL LABORATORY,
*Madison, Wisconsin, September* 18, 1883.

DEAR SIR: I have the honor to present to you the accompanying report on the flora of Caroline Island, based upon the collection made under your direction by Dr. DIXON, U. S. N., and submitted to me for examination.

Very respectfully,
WILLIAM TRELEASE.

Prof. E. S. HOLDEN.

*REPORT ON THE COLLECTION OF PLANTS MADE BY DR. DIXON, U. S. N.*

(By WILLIAM TRELEASE.)

The following list comprises the entire flora of Caroline Island, wild and cultivated, exclusive of Algae, of which but one specimen was preserved by Dr. DIXON. In one or two cases no specimens were collected. The identification of these species (inclosed in the list in parentheses) rests upon the collector. In naming the collection I have been much indebted to Dr. ASA GRAY, whose profound knowledge of the South Sea flora has rendered possible the identification of several species which were represented by very imperfect specimens.

The species not included in the botany of the WILKES exploring expedition are marked with an asterisk in the list. With the single exception of Fleurya ruderalis, which was collected on the island adjacent to that occupied by the Eclipse party, the plants are from the island occupied by the party.

Beside the species enumerated, one lily, or amaryllis ("No. 4"), was collected, of which the collector says: "Flower, 4 inches long, white, with brown lines, etc. Specimen destroyed, nearly. Stalks 18 inches high, bright green." The material is insufficient for identification.

CRUCIFERÆ.

*Lepidium piscidium*, Forst., Prodr., 249.
"Pepper-grass, No. 9."

PORTULACEÆ.

(*Portulaca*, Sp.)?

"Two varieties of portulaca" recognized.

GUTTIFERÆ.

*Calophyllum inophyllum*, L., sp., 732.

"Wood capable of high polish, No. 8."

MALVACEÆ.

*Sida fallax*, Walp., Rel. Meyen., 306.

"Only one specimen found, No. 6."

SIMARUBEÆ.

*Suriana maritima*, L., Spec., 284.

PASSIFLOREÆ.

*Carica papaya*, L., Sp., 1466.

Cultivated for its fruit.

CUCURBITACEÆ.

*(*Cucurbita pepo*., L., Spec., 1435.)

Recognized in cultivation.

RUBIACEÆ.

**Morinda citrifolia*, L., Spec., 250.

"Height of tree, 15–20 feet; branches low; No. 1."

BORAGINEÆ.

**Cordia subcordata*, Lam., Ill., 1899.

"Tree, soft, high; lower branches touching the ground."

**Tournefortia argentea*, L. fil., Suppl., 133.

"Eight feet high, clumpy, light green."

**Heliotropium anomalum*, Hook. and Arn., Bot. Beech. Voy., 66.

"Six inches to 18 inches in height; flowers white; No. 3."

SCROPHULARINEÆ.

**Russelia juncea*, Zucc., Flora, 1832, II., Beibl., p. 99.

"One specimen only. Ground, and over tree stumps; No. 2." A native of Mexico, probably introduced for its flowers, as it is widely cultivated.

NYCTAGINEÆ.

**Boerhaaria*, Sp.?

"Vine creeping over ground and coral rock; leaves light green." Represented by a fragment which does not admit of further identification.

**Pisonia grandis*, R. Br., Prodr., 422.

"A large tree, 40 or 50 feet high, with a trunk 4 feet in diameter."

CHENOPODIACEÆ.

**Boussingaultia baselloides*, H. B. K., Nov. Gen. et Spec., VII., 194.

"Vine climbing over portico."

EUPHORBIACEÆ.

**Euphorbia pilulifera*, L., Amoen. Acad., III., 114.

**Phyllanthus Niruri*, L., Spec. Pl., 1392.

URTICACEÆ.

**Ficus carica*, L.

Cultivated for its fruit.

*Fleurya ruderalis*, Gaud., Voy. Urania, 497.

BROMELIACEÆ.

**Ananas sativa*, Schult., Syst. Veg., VII., 1283.

Recognized in cultivation.

PALMÆ.

*(*Cocos nucifera*, L., Flor. Zeyl., 391.)

Recognized in cultivation.

PANDANEÆ.

(*Pandanus*, Sp.)

No specimens were collected, but I learn from the notes of the collector, and from Professor HOLDEN, that one or more of the screw pines were found growing in various parts of the island.

GRAMINEÆ.

* ? *Panicum* (*Digitaria*) *marginata*, Lk. ?

Apparently identical with No. 6 of WILKES Expl. Exp., from Cape Verde Island, in the Gray herbarium, but in poor condition.

**Eleusine Indica*, Gaertn., Fruct., I., 8.

**Eragrostis plumosa*, Lk.

**Lepturus repens*, R. Br., Prodr., I., 207.

FILICES.

**Polypodium phymatodes*, L., Mantissa plant., 360.

ALGÆ.

**Halimeda triloba*, Deng.? One specimen collected by Mr. UPTON.

FUNGI.

**Glœosporium Calophylli*, n. sp.

On fruit of *Calophyllum inophyllum*, L. Spores unicellular, elliptical or oblong, straight or somewhat curved, obtuse at both ends; coarsely granular or with a few large oil globules; $4 \times 18\ \mu$, oozing out in salmon-colored masses."

§ 6. NOTES ON THE ZOÖLOGY OF CAROLINE ISLAND BY DR. DIXON, U. S. N.

The following notes on the zoölogy of the island were furnished by Dr. DIXON.

"Although remotely situated and rarely visited by man, these insignificant points of land—mere dots upon the bosom of the broad Pacific—are, in some particulars, well stocked with representatives of the animal kingdom. They cover a wide range in class, order, genus, and species. An enormous number of birds occupy several of the islets; and being devoid of fear, or perhaps ignorant of human enemies, a few of them permitted handling without an effort on their part to escape until after their capture had been effected.

While nature has been lavish in the bestowal of gorgeous colors to almost everything about these coral formations, yet the plumage of the birds is remarkably plain. The members of the feathery tribe, covering a small scope, may be classified thus:

ORDER: *Grallatores:*

Plover.

Heron (probably *Ardea jugularis*, two varieties, brown and white.)

Curlew.

Snipe.

ORDER: *Longipennes:*

Seagull, two species.

Terns, two species (one with all the feathers white, and the noddy.)

ORDER: *Totipalmes:*

Gannet.

Booby.

Frigate bird.

There were great numbers of the frigate bird on several of the islets; and there appeared to be two distinct varieties, one with a large red pouch, the throat being white. The pouch could be wrinkled to a very small size. One, with pouch, was seen to swoop down from a high tree, in which were numerous nests, to the lagoon, make three distinct scoops in water and then return homewards with pouch enlarged. Professor HOLDEN reports hearing the notes of a singing bird, but he did not see the bird.

The insects are numerous, but cover a limited range.

ORDER: *Coleoptera:*

Beetle.

Weevil.

ORDER: *Orthoptera:*

Cockroach.

Croton bug. The Eclipse Expedition is probably responsible for adding at least one member to the insect family, for many croton bugs appeared when stores and instruments were unpacked.

House cricket.

Grasshopper.

ORDER: *Hymenoptera:*

Ants, two varieties, and very numerous.

ORDER: *Lepidoptera:*

Butterfly, a dozen or more varieties. A collection of the butterflies was made by M. PALISA and presented to Professor HOLDEN.*

Moth, several species and very numerous.

ORDER: *Homoptera:*

Plant lice.

ORDER: *Diptera:*

Gnat.

Flesh fly. Domestic fly. Very numerous; a small fly; yellowish; very quick in its movements and generally found in the presence of decaying animal matter.

The Saurian reptiles have but one representative, the lizard, of which there are three species. The Chelonian reptiles are represented by one family of sea-tortoise or turtle, which, however, is not very numerous.

The Arachnidans make also but a single exhibit in the spider, of which there are two species. Contrary to expectations, only one centipede was seen, the giant representative. The brown rat has a foot-hold, but is not numerous. Their nests were made in the cocoa-nut trees, just at the base of the fronds.

There must be some connection between color and tropical heat, because even the most contemptible things possess chromatic gifts that make them attractive. Fish are given the most marvellous embellishment, the variety of color combinations being infinite. Not a tint is out of place, nothing is harsh or strained, and the quiet pools within the outer reef, occupied by living

* A memorandum on the butterflies follows this section.—E. S. H.

gems of blue, gold, silver, and green, make a picture never to be forgotten. Many of the fish are timid, and dart quickly away upon the slightest provocation, while others appear indifferent to capture, and may be easily caught with the hand.

The basins and indentations of the outer reef afford safe retreats for many wonderful forms that live in these warm seas. A view of such a grotto, with its growing coral and brilliant and gaudy fish, fully confirms the praise bestowed by nearly all visitors to these South Sea Islands. Even the shark, eel, gar-fish, and other common forms have their charming gifts, only in less degree than the chætodon and parrot-fish.

The coral reef is a field pregnant with life, and offering the most beautiful and curious forms imaginable for observation and study.

Detached pieces of coral form the hiding places of hosts of small fish, crabs, shrimps, star-fish, mollusks, etc., and myriads of microscopic beings. The following list is only a partial inventory of the different forms observed:

*Echinoderms:*

Brittle stars (*ophiuridæ*), several varieties.

Star-fish (*Asteridæ*) { sun star. / cross fish. / knotty cushion star.

Sea urchins (*echini*), six varieties.

Sea cucumbers (*holothuriæ*), three varieties.

*Crustaceans:*

ORDER: *Decapoda:*

Sea crayfish.

Shrimp.

Racer crab (Ocypoda).

Land crab (gecarcinus).

Hermit crab, three species, which occupied eight varieties of mollusk shells. Their number is enormous. They were found even near the tops of small trees, whither they had gone carrying a shell of several times their own weight.

Of the Cephalopods the only one seen belonged to the family of the Octopodidæ, the eight-armed cuttle.

Although the habitat of many varieties of mollusks, we had not the facilities for procuring many of their shells, and some seen could not be identified. The following list, therefore, is not a complete one:

Sea trumpet (Triton).
Frog shell (Ranella).
Spindle shell (Fusus).
Spotted needle shell (Terebra).
Cowrie (Cypræidæ), eight varieties.
Common top shell (Trochus).
Pinna (Pinna).
Scallop (Pecter), several varieties.
Cup and saucer limpet (Calyptræa).
Clams (Tridacnidæ), and others.
Stromb shells (Strombus), several varieties.
Whelks, volutes, etc."

## MEMORANDUM OF THE BUTTERFLIES, ETC., OF CAROLINE ISLAND.

(Collection by Dr. PALISA; identifications by Dr. ARTHUR BUTLER and Mr. HERMANN STRECKER.)

Dr. PALISA, of the French expedition, made a complete collection of the lepidoptera of the island, which he has taken to Vienna for identification. At my request, he was kind enough to make as complete a collection as was possible of duplicates, which were presented to us. This latter collection contained thirteen specimens, and through the kindness of my colleague, Professor OWEN, of the University of Wisconsin, it was submitted to Dr. HERMANN STRECKER, of Reading, Pennsylvania.

Dr. STRECKER was prevented from making a careful study of the collection, and returned it with the identification of five specimens, viz:

1 *Utethesia pulchella*, L.

4 *Diadema bolina*, 3 ♂, 1 ♀.

One of the latter (a male) and the other eight specimens were sent by me to Dr. ARTHUR G. BUTLER, assistant keeper of the zoölogical department of the British Museum. The remaining four were presented to Professor OWEN'S collection.

Dr. BUTLER kindly undertook the identification of the nine specimens sent him, and his report on the subject follows. These specimens are now in the collection of the British Museum.

It will be seen that Dr. STRECKER'S *Diadema bolina* has been made a new species by Dr. BUTLER, who has also found in this small collection three other new species, one representing a new genus.

I desire to express here the thanks of the expedition to these gentlemen for their kindly interest, and especially to Dr. BUTLER for his full report, which follows:

*THE LEPIDOPTERA COLLECTED BY HERR PALISA AT CAROLINE ISLAND IN MAY, 1883.*

By ARTHUR G. BUTLER, assistant keeper of the zoölogical department, British Museum.

"The collection contains one butterfly of the family *Nymphalidæ;* the moths are represented by a new species of *Macroglossa*, three species of *Noctuæ*, and sexes of one species of *Pyrales.*

BUTTERFLIES.

NYMPHALIDÆ.

*Hypolimnas Holdeni*, sp. n. (No. 61).

♂ wings above, velvety, blackish-piceous, with the sinuations of the cilia white; primaries with a large, irregular, oblique patch of glossy ultramarine blue, inclosing an oblique oval lilac patch, irrorated with white scales immediately beyond the cell; an oblique, unequally trifid, subapical spot, the two upper divisions of which are snow-white, and the inferior division ultramarine, irrorated with lilac; secondaries with a large subquadrate central patch of glossy ultramarine, its inner edge straight, limited by the first median branch, its other edges undulated between each pair of veins; this patch incloses a small central aggregation of lilac scales; abdominal area purplish brown, with pale sandy-brown inner edge; body blackish; head and palpi white spotted; antennal club tipped with bright cupreous; under surface very similar to that of *H. rarite* of Eschscholtz, which we have from North Australia and the Ellice Islands, but wanting the white band across the secondaries; the submarginal lunate spots are also bluer, and the apical area of the primaries is redder; it also differs from *H. otaheitæ* of Felder in the same characters and its greatly superior size; expanse of wings, 75 millimeters.

The genus *Hypolimnas* is a difficult one, chiefly owing to the great similarity of the males. This difficulty is, however, increased in certain islands by the apparently variable tendencies of the females, more particularly in the ground-color of the wings. How far these modifications are constant to locality within the island can only be ascertained by careful breeding; but as regards forms from different islands there can be no doubt that they are locally separable.

In the present day all genera in which the species are common, and the local forms of which consequently are fairly well represented in all extensive collections, are the subject of endless and useless discussion between the two classes of describers—those who regard local forms as species and those who regard them as varieties. As a fact, however, the matter lies in a nutshell. If all local forms are varieties, there are no species of Lepidoptera, or will not be when we have perfect collections. Local forms are in fact the only species that exist, as is evident in the case of all genera which are well represented in our collections. I therefore regard a local form as a species and a sport, a melanism or an albinism as a variety. I admit no subspecies, regarding the latter as an evasion, invented by such as do not possess sufficient courage to express their opinions.

## MOTHS.

### SPHINGIDÆ.

*Macroglossa cinerescens*, sp. n. (No. 57).

♀ Nearer to *M. obscura*, Horsf. from Java, than to any other described species; differing from all the known species in the coloration of the primaries; the latter are ash-gray; the costal border dark brown, with a basal streak in the cell and a spot (confluent with costal border) at the end of the cell of the same color; a broad, smoky-brown, external border, widest on costa and gradually narrowing to external angle, its inner edge darkest, forming an ill-defined band; secondaries dark chocolate-brown, traversed from center of costa to anal angle by a broad, bright, ochreous band, its inner edge dentated, its outer edge sinuous (geschwungen); body grayish-brown above, the abdomen evidently with yellow lateral spots, but the body of the type is a good deal rubbed, having lost its lateral and anal tufts; wings below smoky-brown, inclining to chocolate; primaries with paler internal border; base streaked with whitish; secondaries whitish at base; abdominal area chrome yellow, excepting at anal angle; a broad pale band, mottled with red-brown, from the abdominal area to the costa; head below white; pectus sordid white; venter smoky grayish-brown, with white-fringed black-edged posterior margins to the segments; expanse of wings 48 millimeters.

The genus *Macroglossa* contains a considerable number of nearly allied species, no less than thirty-seven being contained in the collection of the British Museum. When the whole of the grades can be associated in one series it is probable that they will not number less than a hundred, possibly many more. Notwithstanding the great similarity of the imagines in this genus, the larva exhibit the most astounding differences of color and pattern.

### XYLOPHASIIDÆ.

*Prodenia retina* (Nos. 60 and 62).

*Neuria retina*, Herrich-Schäffer, Europ. Schmett, II, p. 292; Noct., pl. 29, fig. 145.

This is a wide-ranging species, of which the following may be nothing more than an albinism; but as I have never seen anything like it before from any of the Asiatic or African localities where *P. retina* abounds, I think it worth while provisionally to give it a distinctive name.

*Prodenia evanescens*, sp. n. (Nos. 59 and 63).

Slightly larger than *P. retina*, with the same pattern, but the primaries, with all the brown markings, replaced by pale olivaceous; the black markings also indicated in this color upon the central belt, but towards base and external border by dull lilac, if indicated at all; veins beyond the central belt dull lilac; secondaries semi-transparent, opaline white as usual, but the brownish border much paler, of a pale brassy-golden tint; expanse of wings 34–37 millimeters.

In the genus *Prodenia* there is a considerable similarity of pattern in most of the species, so that the distinctness of *P. evanescens* is quite possible.

### REMIGIIDÆ.

*Remigia frugalis* (No. 58).

*Noctua frugalis*, Fabricius, Ent. Syst. III, 2, p. 138.

*Chalciope lycopodia*, Hübner, Zutr. Exot. Schmett. p. 25, n. 119; figs. 897, 898.

This is a wide-ranging species, common throughout Asia and Africa.

Allied to *Mesocondyla*, Led., and *Ceratoclasis*, Feld.

### BOTIDIDÆ.

*Rinecera* gen. nov.

Primaries triangular, broader in the male than the female, and with the costal border angularly expanded, thickened at the edge to basal third, where it is succeeded by a rather deep impression, bounded in part by a well-defined ridge; costal vein short, extending to the angle at extremity of thickened basal border; cell open, short in the male, extending to about the basal third; slightly longer in the female; subcostal vein five-branched; the first branch emitted before the end of the cell; in the male near to base and much abbreviated; second to fourth branches beyond the cell from main stem; the second branch in the male emitted at some distance beyond the cell; the fourth branch running to apex in continuation of main stem; fifth branch emitted separately from anterior angle of cell and close to upper radial; the two latter nervures are elbowed and widely divergent in the male; discocellular veinlet obsolete; the lower radial and the three median branches are emitted close together, so that the median vein becomes quadriramose; submedian normal; secondaries cuneiform, with angles rounded off, narrower and more elongated in male than female; costal margin in male about as long again as abdominal margin; frenum long, single, held by a broad upcurved patch of long scales near base of inner border of primaries; costal vein obsolete; subcostal thickened toward base, emitting its two branches from a long footstalk beyond the cell; the latter short, closed by a feebly indicated incurved discocellular veinlet; two radials present (probably to compensate for loss of costal vein); upper radial emitted from anterior angle of cell, and lower as a fourth median branch from posterior angle of the same; body moderately robust; eyes large and prominent; palpi extending considerably in front of head, porrected, nearly straight, compressed, compactly scaled, terminal joint very short; antennæ long and wiry, extending to about second third of primaries; in male very aberrant, the basal joint subcylindrical, slightly compressed, a little attenuated in front; second joint more than twice as long as first, straight, slightly contorted at proximal end, expanded and terminating in a tuft of bristles at distal end; inferior margin flattened, coarsely serrated, and fringed with short bristles; third joint slightly longer than first, slightly curved, cylindrical, expanding toward distal end, clothed with long scales; remaining joints normal, tapering toward extremity; legs long and moderately robust, femora compressed, tibial spurs well developed; abdomen of male wanting, of female extending slightly beyond secondaries, tapering to anal extremity.

*Rinecera mirabilis* sp. n. (Nos. 64 and 65).

Fuliginous-brown, paler in male than female; discoidal spots of primaries black, centered with hyaline white, most distinctly in female; an angulated black band across basal fourth; discal band extremely irregular ≷-shaped, black, with yellow and white external border; fringe gray, heavily spotted with black at base; a cream-colored spot at extremity of first median branch; secondaries crossed in the middle by a broad black Y-shaped band, the furca of which is filled by a hyaline-white spot, the outer edge partly margined with yellowish white; a white bordered oblique black ≷-shaped subapical stripe; fringe white, with an interrupted black basal stripe; a creamy white spot at extremity of first median branch; body above fuliginous-brown, metathorax white; antennæ and legs of male whitish with blackish bands; of female pale brown; the legs whitish below; venter white; wings of male below suffused with white, so that the markings, especially of the primaries, are extremely indistinct; expanse of wings ♂ 19 millimeters, ♀ 16 millimeters.

In general appearance this species somewhat resembles FELDER'S *Ceratoclasis barbicornis*, next to which, I think, it ought to stand."

### IDENTIFICATION OF THE SPECIMENS OF DR. PALISA'S ORIGINAL COLLECTION.

A letter received from Dr. PALISA, dated Vienna, December 1, 1883, gives a brief account of the identifications of his collection of 15 specimens, which have been made by Professor ROGENHOFER.

1. *Diadema bolina*, L.
2. *Cyllo* (*Melanitis* Fab.), Leda L., var. *taitensis*, FELD.
3. *Sphynx convolvuli*, L.
4. *Macroglossa*.
5. *Utethesia pulchella*, L.
6. *Prodenia*, sp.
7. *Spodoptera achronyctoides*, GUL.
8. *Achaea Melicerte*, Am., v. *ligrina*, FAB.
9. *Remigia frugalis*, FAB.
10. *Botys*.
11. *Botys phaeopteralis?*
12. *Aethaloëssa meridionalis*, WALK.
13. *Ceratoclasis*, new sp.
14. *Hymenia* (*Zinkonia*) *albifascialis*.
15. *Tinea*.

### § 7. CHEMICAL CONSTITUENTS OF THE SEA-WATER IN THE LAGOON AT CAROLINE ISLAND.

(Determined by Messrs. STILLWELL AND GLADDING.)

A sample of water from the lagoon was brought home by Mr. UPTON and submitted for chemical analysis to Messrs. STILLWELL & GLADDING, analytical and consulting chemists, New York. The following is their report of the analysis:

"NEW YORK, *August* 8, 1883.

"Result of analysis of a sample of lagoon water from Caroline Island:

| | Per cent. |
|---|---|
| Chlorine (duplicate determinations) | 1.895<br>1.896 |
| Calcium oxide | 0.057 |
| Magnesium oxide | 0.220 |
| Sulphuric oxide | 0.219 |

"For the purpose of comparison we append analyses of ocean water, by FORCHHAMMER, taken from Watts' Chem. Dict., vol. VIII, p. 2135; by SCHMELCK, from Science, vol. II, p. 12, and analysis of water from the Irish Channel, Watts' Chem. Dict., vol. VIII., p. 2135.

| | Chlorine. | Calcium oxide. | Magnesium oxide. | Sulphuric oxide. |
|---|---|---|---|---|
| | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| Lagoon water, STILLWELL & GLADDING | 1.895 / 1.896 | 0.057 | 0.220 | 0.219 |
| Ocean water, FORCHHAMMER | 1.986 | 0.059 | 0.220 | 0.236 |
| North Atlantic, SCHMELCK | 1.930 | 0.057 | 0.220 | 0.221 |
| Irish Channel, THORPE & MORTON | 1.873 | 0.057 | 0.203 | 0.218 |

"Very respectfully,

"STILLWELL & GLADDING.

"Mr. WINSLOW UPTON, *Washington, D. C.*"

Mr. UPTON has kindly forwarded this note, with the following memorandum:

"The analysis was limited to the four principal constituents on account of the small quantity of water available. It will be seen that the essential difference between the analysis and the others given is the amount of chlorine, which was estimated twice by very careful duplicate analyses. The lagoon water is more like that from the Irish Channel than like ocean water; that is, it is slightly *fresher*. Since the lagoon has free outlets it is presumable that a similar analysis would have resulted from water taken from the ocean in the vicinity."

## V.—OBSERVATIONS OF 23 NEW DOUBLE STARS BY MESSRS. HOLDEN AND HASTINGS.

During our stay on the island Dr. HASTINGS and myself spent two or three hours of each clear night (with a few exceptions) in examining the southern sky, which is filled with objects of great interest to an observer who has only seen the stars visible from northern latitudes.

In the course of this examination the following list of 23 new double and 5 new red stars was found. Our days were usually full of work, and more time was not spent in the observatories at night as it was impossible to have a quiet sleep in the day-time, owing to our contracted quarters.

It is clear, however, from this short list, that a stay of a year or two in the southern hemisphere would yield a rich return to an observer who went properly equipped. Probably Quito or Santiago de Chili would be the most eligible station.

During the voyage from Callao to Caroline Island, and from the island to Honolulu, Mr. UPTON made a number of observations of variable stars, which will be communicated by him to the Harvard College Observatory.

*List of 23 new double stars discovered at Caroline Island between April 27 and May 7, 1883, by* E. S. HOLDEN *and* C. S. HASTINGS.

| Star. | α 1880.0. | δ 1880.0. | p. | s. | Mags. | Observer. | Date, 1883. |
|---|---|---|---|---|---|---|---|
| | h. m. s. | ° ′ | ° | ″ | | | |
| Stone 5791 | 10 28 35 | —54 46 | 250 | 2 | 8.5— 9 | HOLDEN. | May 1. |
| Anon. | 11 31 28 | —60 14 | 350 | 1½ | 8.5— 9.5 | HOLDEN. | April 28. |
| Lac. 4936 | 11 48 58 | —55 25 | 230 | 2 | 7.5— 8 | HOLDEN. | May 1. |
| Anon. | 11 57 40 | —57 5 | 240 | 1½ | 8.5— 9.5 | HOLDEN. | May 4. |
| Lac. 5223 | 12 31 24 | —55 16 | 205 | 1¼ | 7.3— 9.3 | HOLDEN. | May 1. |
| Anon. | 13 1 16 | —52 5 | 200 | 1¼ | 9.5— 9.5 | HOLDEN. | May 4. |
| Lac. 5434 | 13 6 59 | —62 57 | 40 | 1½ | 7.5—10 | HOLDEN. | May 6. |
| Lac. 5738 | 13 48 28 | —53 33 | 348 | 1 | 5 — 6 | RUSSELL No. 227. | May 2 A. B. |
| | | | 296 | 25 | 6.5—13 | HOLDEN. | May 2 A. C. |
| Lac. 5817 | 13 59 56 | —49 18 | 30 | ¾ | 7.5— 7.5 | HASTINGS. | May 1. |
| Lac. 5844 | 14 6 14 | —61 9 | 180 | 3½ | 7 — 9 | HASTINGS. | May 2. |
| Lac. 6066 | 14 41 16 | —72 42 | 90 | 1½ | 6 — 8 | HASTINGS. | May 2. |
| Lac. 6136 | 14 50 35 | —67 30 | 0 | 5 | 7 —10 | HASTINGS. | April 27. |
| Anon. | 15 2 18 | —40 31 | 70 | 4 | 7 — 8 | HASTINGS. | May 4. |
| Stone 8250 | 15 3 33 | —51 38 | 220 | 3 | 7.5— 9 | HOLDEN. | May 2. |
| Lac. 6259 | 15 6 36 | —60 27 | 300 | 12 | 6.5—13 | HASTINGS. | April 27. |
| Anon. | 15 7 20 | —68 8 | 0 | 1¼ | 7.5— 9 | HASTINGS. | May 2. |
| Anon. | 15 8 40 | —53 50 | 170 | 3 | 8 —10 | HASTINGS. | May 1. |
| Stone 8348 | 15 14 18 | —47 29 | 225 | 1½ | 8.0— 8.5 | HASTINGS. | May 1. |
| ε Lupi | 15 14 32 | —44 15 | 175 | ¾ | 3 — 6 | HASTINGS. | April 27. |
| Lac. 6488 | 15 36 11 | —50 21 | 210 | 2 | 7 — 9 | HOLDEN. | May 4. |
| Lac. 6540 | 15 44 44 | —60 23 | 85 | 1 | 6.5— 9 | HASTINGS. | May 2. |
| Stone 9221 | 16 50 15 | —56 25 | 125 | 2 | 7.5—10 | HOLDEN. | May 7. |
| Lac. 7315 | 17 23 16 | —40 57 | 95 | 1 | 8.0— 8.5 | HOLDEN. | May 7. |

*List of 5 new colored stars discovered at Caroline Island by* E. S. HOLDEN.

| Star. | α 1880. | δ 1880. | Remarks. | Stone's mag. |
|---|---|---|---|---|
| | h. m. s. | ° ′ | | |
| Lac. 5384 | 12 58 28 | —51 28 | Reddish; 7.5 magnitude. | 6 |
| Anon. | 13 10 24 | —63 57 | Brick-red; 7.7 magnitude. | — |
| θ Apodis. | 13 53 41 | —76 13 | Fine orange red; 5 magnitude. | 5 |
| Lac. 7152 | 17 4 5 | —56 14 | Red; 7.0 magnitude. | 6 |
| Lac. 7638 | 18 12 10 | —61 33 | Orange red; 6.0 magnitude. | 5.4 |

It will be observed that my estimates of magnitude are in general about one magnitude smaller than Stone's. The latter are to be preferred, as I was not familiar with the appearance of stars in the 6-inch telescope.

## VI.—PLANS FOR WORK ON THE DAY OF THE ECLIPSE, ETC.

(By Prof. E. S. HOLDEN.)

General instructions as to the plan of work were given to me by the committee of the National Academy of Sciences, but the details of carrying out their intentions were left to me.

It is my opinion that the very short time of the totality of a solar eclipse should be utilized by any one observer in making a single observation, or at least a single kind of observation. The time, even of the longest totality, is all too short, and if it is further diminished by the times required to move from one instrument to another, or to change apparatus, the real value of the observations which are made is seriously lessened. It was, therefore, my effort to assign to each observer one single piece of work, which he could reasonably hope to accomplish, so that his results would have a perfectly definite meaning.

I very much regret that the excellent photographic apparatus constructed under the direction of Prof. W. HARKNESS, U. S. N., for the Naval Observatory, was not utilized on this expedition. From the results obtained with it in 1878, even before its modification into its present form, I have no doubt but that observations of great value could have been secured. As it was, the entire field of photography was left to the English party which accompanied our own, and I must refer to the memorandum of Mr. LAWRANCE, which accompanies this report, for a preliminary account of their preparations and valuable results. Photography of the corona, etc., was also employed in a very successful way by the French expedition under M. JANSSEN.

The plan of the American party proper comprehended—

(A.) A search for the interior planet (or planets) *Vulcan*, reported by Professor WATSON and also by Professor SWIFT. This was assigned by your committee to me.

(B.) Spectroscopic observations of the inner and outer corona.

This was undertaken by four observers, namely Dr. HASTINGS, Mr. ROCKWELL, Mr. UPTON, and Ensign BROWN. The general plan of the spectroscopic and polariscopic observations was discussed by Dr. HASTINGS and myself with the other observers, but the entire credit for the details of the observations belongs to Dr. HASTINGS and to the observers themselves who were placed under his directions.

(C.) Polariscopic observations of the corona.

At my request Dr. HASTINGS brought with him the polariscope which he used at the eclipse of 1878, for the purpose of attaching it to one of the spare telescopes of the party, and it was my hope that a satisfactory set of observations might be obtained, especially because the observations with this instrument in 1878 had led to the conclusion of tangential polarization.

Mr. PRESTON was placed under the exclusive direction of Dr. HASTINGS for this duty, his observations to be made during that part of totality after his observations of the time of second contact and before his observation of third contact.

The telescope was pointed by Midshipman DOYLE, and during totality Mr. PRESTON made 11 pointings. When these were reduced they showed that the apparatus itself, *i. e.*, the combination of the telescope and the polariscope, was not suitable to its object, as a subsequent examination convinced Dr. HASTINGS and myself. I regret that this should not have been found out beforehand, so that the services of such a competent observer as Mr. PRESTON might have been utilized. The observations are not here printed.

(D.) Telescopic examination of the details of the inner corona.

This was made by Dr. W. S. DIXON, U. S. N., with the 3½-inch CLARK telescope lent to us by the Nautical Almanac office. A drawing of the corona with a description is given in Dr. DIXON's report.

(E.) Observation of the contacts.

The *first contact* was observed by Messrs. UPTON, PRESTON, and BROWN.

The *second* by Mr. PRESTON.

The *third* by Mr. PRESTON.

The *fourth* by Messrs. HOLDEN, ROCKWELL, UPTON, PRESTON, and BROWN.

The observation of the contacts was made entirely subordinate to more important work.

(F.) The determination of the latitude.

This was determined on four nights by 16 pairs of stars, by TALCOTT's method, by Messrs. PRESTON and BROWN. Mr. UPTON also determined a preliminary value with the sextant.

(G.) The determination of the longitude.

1st. By transport of chronometers. Five chronometers were carried by the expedition from New York to San Francisco, and kept running constantly. These were in charge of Mr. UPTON for nearly the entire time, and their comparisons, as well as the computations relating to time and longitude, were made by him and are detailed in his report. Time-sights with the sextant were obtained by Ensign BROWN at Colon, and at Caroline Island and Honolulu by Mr. UPTON. The entire expedition is indebted to Mr. UPTON for the care and regularity of his work. He also made many of the preliminary reductions of the time observations with the transit, and in fact cheerfully assumed, in addition to his regular work, nearly all of the routine work, which was not originally assigned to him.

2d. By moon culminations. Corresponding observations were made at the United States Naval Observatory and at Caroline Island by Mr. PRESTON. These have been reduced by Mr. UPTON.

(H.) Time signals during totality.

For the photographic operations of the English expedition an elaborate programme of time signals was necessary for the twenty-five minutes including totality, and this thankless but important duty was assigned to Midshipman FLETCHER, U. S. N., who performed it in his usual thorough manner.

(I.) Meteorological observations.

In connection with his full series of hourly meteorological observations, Mr. UPTON undertook a special series during the progress of the eclipse. For details in regard to these I must refer to his important reports on the subject.

(J.) Photographic observations.

The two English observers were expected to carry out a most elaborate programme, involving the exposure of over sixty plates with three instruments. To aid them in their work Lieutenant QUALTROUGH, U. S. N., volunteered to take charge of the photoheliograph, which he did with the assistance of Seaman Gunner HORACE YEWELL.

(K.) Miscellaneous observations.

Observations on the botany and zoölogy of Caroline Island were made during our stay on the island by various members of the party, especially by Dr. DIXON and Mr. UPTON. Their results are given in the appropriate place. I would especially refer to the careful survey of the island which was made by Midshipmen FLETCHER and DOYLE, under the direction of Lieutenant QUALTROUGH. The principal results of this survey are given in the map of Caroline Island.

## VII.—REPORTS ON THE ECLIPSE OF MAY 6, 1883.

### (a) *REPORT OF PROFESSOR EDWARD S. HOLDEN.*

To Professor C. A. YOUNG,

*Chairman of the Eclipse Committee of the National Academy of Sciences:*

MY DEAR PROFESSOR YOUNG: In accordance with the instructions of your committee I confined my work at the eclipse to the search for a possible *Vulcan* or *Vulcans*, such as were reported by Prof. J. C. WATSON and Prof. LEWIS SWIFT at the eclipse of 1878.

By the kindness of the regents of the University of Wisconsin I was allowed the use of the 6-inch CLARK telescope of the Washburn Observatory. This telescope formerly belonged to Mr. S. W. BURNHAM, and by means of it over four hundred double stars have been discovered, which is a sufficient proof of the excellence of its objective. I employed in connection with it the zone eye-piece of the 15½-inch refractor of the Washburn Observatory. This gave me a magnifying

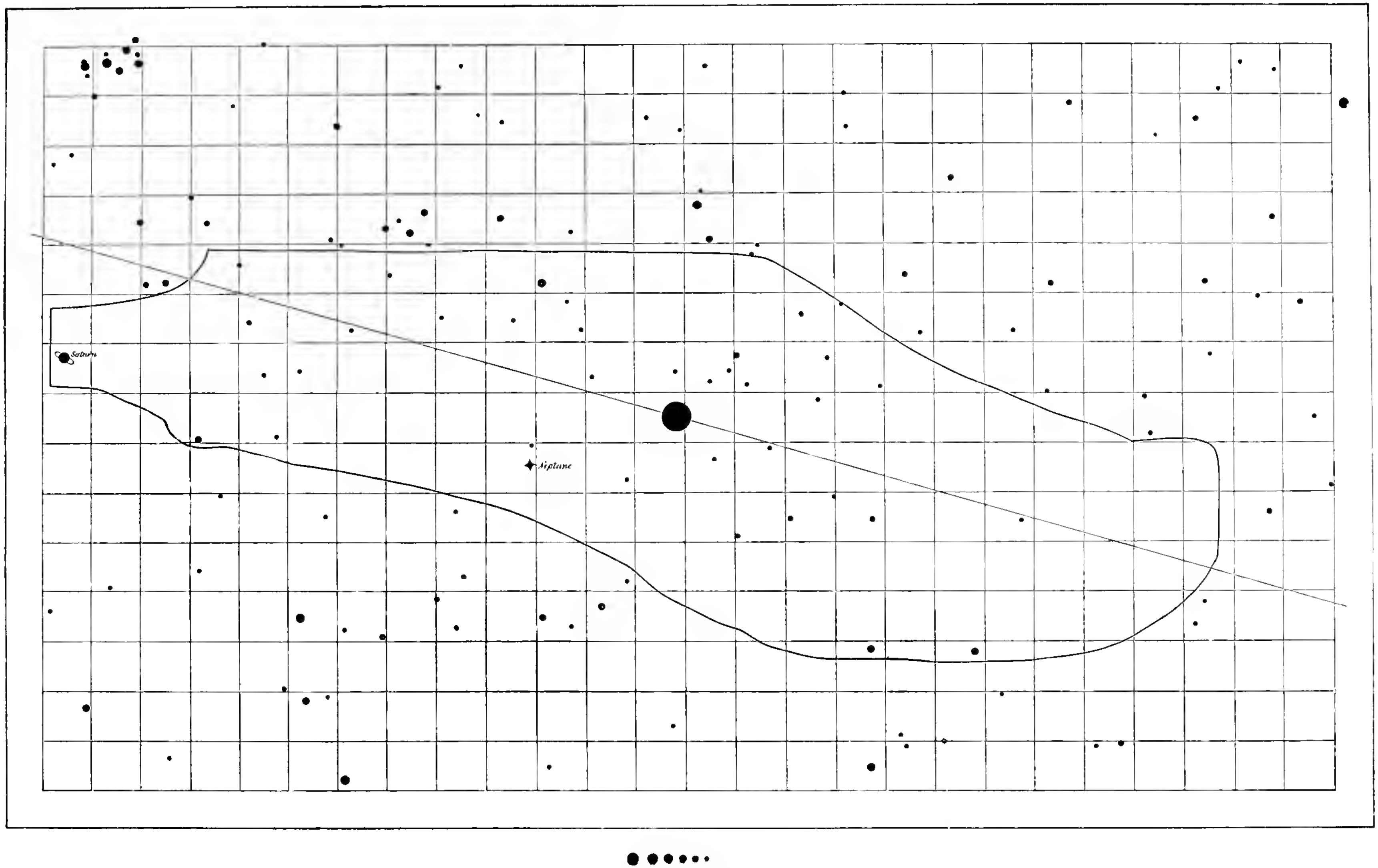



FIG. 20.—MAP OF PLANETS AND STARS NEAR THE SUN, MAY 6, 1883.

power of 11 diameters and a field of view 54′ (in declination) by 237ˢ (in right ascension). This magnifying power utilizes the whole aperture of the objective.

I prepared a map of the planets and stars in the neighborhood of the sun on May 6, which was published in *Science* No. 3, for February 23, 1883. I arranged my plan of observation so that I could make sweeps in right ascension, each sweep being about 54′ wide in declination. To this end I memorized all the stars in each sweep in order and in magnitude.

Some of the sweeps were longer than others, so that the ecliptic and its neighborhood should be covered without wasting time. In order that the entire time of the totality might be available for the search, I did not observe the second and third contacts; and I did not observe the first contact, as this observation would have made it necessary to take off my zone eye-piece and thus to lose the adjustment for parallel and focus I had made on the night of May 5.

I need not describe the mechanical arrangements I had provided for determining the position of any object not on my star-map, since these were not employed. They were, however, adequate for the purpose. On May 6 I began sweeping a few seconds after totality commenced, and swept carefully and deliberately over the space marked on the accompanying map without finding any new object. I am positive that no star as bright as five and a half magnitude could have escaped me. I saw all the sixth magnitude stars within this space except the three nearest the sun. I saw no seventh magnitude stars anywhere.

The star D. M. (19°, 477), in right ascension $3^h\ n^m\ 21^s$, and declination $+\ 19°\ 41$, was very bright indeed, and no star half or even a third as bright could have by any possibility escaped observation. This star is of four and two-tenths magnitude; the same as the brighter of the two planets reported by Professor WATSON in 1878.

At the eclipse of 1878 it was a question whether the planet *Vulcan* of LE VERRIER existed or no. At the eclipse of that year I searched for such a planet over a space of 320 square degrees and found none. The *Vulcan* of LE VERRIER should have been at least of the third magnitude. My instrumental means were sufficient to have detected it had it existed.

At the same eclipse Professor WATSON reported the existence of two new and much smaller bodies which he saw with a 4-inch telescope with a magnifying power of 45. Professor SWIFT also reported the existence of two different (and new) bodies.

At the present eclipse I looked for these with a magnifying power purposely chosen the same as Professor WATSON'S, and with an objective giving more than twice the light of a 4-inch. No such new bodies existed within the space marked on the map. It is my opinion, therefore, that at future eclipses it will not be necessary to devote an observer and a telescope to the further prosecution of this search, and I must regard the fact of the non-existence of *Vulcan* as definitively settled by Dr. PALISA'S observations and my own.

### CONTACTS.

I observed the fourth contact with an aperture of 6 inches, power 57, at $4^h\ 6^m\ 34^s.8$ of chronometer 1536 NEGUS. Its correction to Caroline Island sidereal time was $+\ 1^m\ 59^s.5$: so that the fourth contact occurred for me at $4^h\ 8^m\ 34^s.3$ Caroline sidereal time $=1^h\ 10^m\ 13^s.8$ Caroline mean time.

### OBSERVATION OF THE DIFFRACTION-BANDS BEFORE AND AFTER THE TOTAL PHASE.

I had a white tent-fly stretched flat on the ground a few feet south of my observatory, and I employed the two carpenters of our party in observing the direction and the distance apart of the bands.

The seams of the tent were plainly visible during the totality; they were 20 inches apart and ran exactly north and south.

Carpenter's Mate CHARLES EMMS, of the *Hartford*, stood near the tent and compared the distance between the centers of two adjacent diffraction-bands with the distance between the seams and with a foot rule which he held in his hands. He estimated this distance *before* totality to be 12 inches, and *after* totality to be 18 inches. I have great confidence that the truth lies between these limits. He also estimated the number of bands passing a given line per minute to be 80. From my recollection of the same phenomenon in 1878, I should think this estimated number too small. The shadows or bands lasted about one and one-quarter minutes, both before and after totality.

While EMMS was observing the distance apart of the bands, Carpenter PETER MURPHY, of the *Hartford*, observed their direction. This he did by laying a 10-foot pole on the tent in a direction perpendicular to the bands. After he was satisfied with the direction of the pole he marked its position on the tent with a pencil. To avoid mistakes the observations before totality were made on the south side of the tent, and those after on the north side.

After the total phase had passed I laid out an east and west line on the tent and compared the directions of the progress of the shadows with this.

*Before totality* the shadows moved along a line whose azimuth was north 60° east.

*After totality* the shadows moved along a line whose azimuth was 92° northwest.

The general direction of motion was west to east before totality and east to west after totality.

The radius of the moon's shadow was about 69 miles. The (observed) direction of motion of the bands before totality was about 16½° to the east of the direction of that radius of the moon's shadow which passed through Caroline Island at second contact.

The (observed) direction of the bands after totality was only 2° to the west of the radius of the moon's shadow which passed through Caroline Island at third contact. It is possible that the first observations are erroneous by 16°, but I do not regard it as probable.

The other scientific work of the expedition is detailed in the following reports.

I am, my dear Professor YOUNG, very sincerely yours,

EDWARD S. HOLDEN.

### (b). *REPORT OF PROF C. S. HASTINGS.*

Prof. E. S. HOLDEN:

DEAR SIR: The late date at which it was definitively determined that the writer should be a member of the Eclipse Expedition rendered the preparation of the apparatus a laborious as well as a most hurried one. The task would, however, have been far more difficult had not the trustees of the Johns Hopkins University generously placed all the facilities of the physical laboratory and the services of the university mechanic at my command. Fortunately much useful apparatus was already in my own possession. This, with that lent either by the university or by Mr. ROCKWELL, one of the members of the party, was all that could be successfully used by the five observers assigned to my instructions. The following is the list of apparatus used, with the essential constants:

APPARATUS.

1. *Polariscope.*—This was the same instrument which the writer used at Central City in 1878; it is fully described in the report on that eclipse published by the United States Naval Observatory. Time did not admit of trying the instrument or even of adapting it to its

telescope before our arrival at the island, but Mr. UPTON took with him a small telescope and its mounting, which there formed a part of the complete apparatus. After the observations on the day of the eclipse it was found that the mounting was too unsteady to admit of the requisite accuracy in pointing, so that, although Mr. PRESTON found polarization in all parts of the corona, the angles of polarization were thoroughly discordant. Of the greatest theoretical importance, however, was the observation that with greater brightness of the field the Savart's bands were more intense. As the instrument is specially devised for the examination of isolated portions of the corona, the inference is that the intensity of polarization does not decrease in approaching the moon's limb.

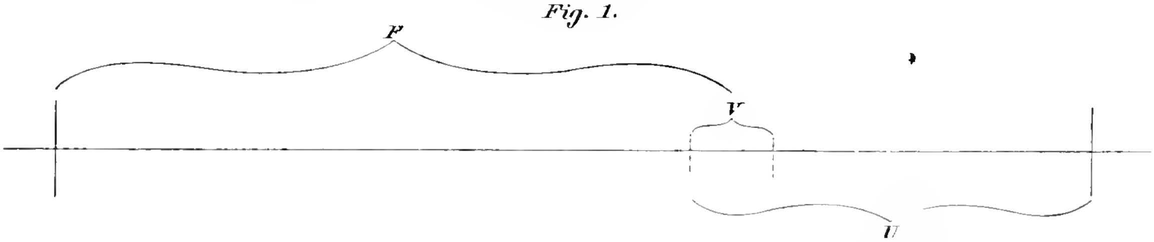
2. *Prismatic telescope.*—This was composed of a large flint-glass prism of 30° before the objective of a telescope lent by Mr. ROCKWELL. The essential constants were as follows: Clear aperture, $2\frac{1}{2}$ inches; apparent length of spectrum (A to H), $22\frac{1}{4}°$; magnifying power used, 29.

The instrument was used by Mr. UPTON, and the results are given in his report.

3. *Integrating spectroscope.*—The instrument belongs to the writer; its constants are given in the report of Ensign BROWN, who observed with it. There is, however, one novelty in its construction which is worthy of notice, because it seems to me better adapted to the end in view than any arrangement before used.

The angular aperture of a small telescope lens, such as would be used for a spectroscope collimator, is rarely less than five or six degrees; consequently, if such a collimator is directed towards a source of light as small as the sun, only $\frac{1}{10}$ or $\frac{1}{12}$ of the whole aperture is utilized. The ordinary method used for correcting this fault since the eclipse of 1870, when Professor YOUNG employed it for the first time, has been to place a small telescope before the slit directed towards the sun. The effect of this addition is obviously to increase the apparent magnitude of the object; it is also evident that the magnifying power of the auxiliary telescope should be, in the case of a total eclipse, about three or four diameters. The only objections to the method are that it requires at least two lenses, and that the system admits of no range of adjustment. I used a single concave lens introduced between the slit and objective of the collimator. It is clear that such a lens would reduce the apparent magnitude of the objective as seen from the slit, and therefore the angular

*Fig. 1.*




aperture of the system. At the same time, the condition that the distance from the objective to the virtual image of the slit formed by the concave lens shall equal the focal length of the collimator is readily satisfied, and this is the only condition for distinct vision. If we set (Fig. 1)

F = focal length of collimator objective,

A = angular aperture of same,

$a$ = angular aperture desired,

$-f$ = focal length of concave lens,

$u$ = distance from concave lens to slit,

$v$ = distance from concave lens to image of slit, and

L = total length of collimator,

the solution is as follows:

The general equation connecting the conjugate foci of a simple lens is

$$-\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$$

where $u$, $v$, and $f$ are to be measured from the lens, and taken as positive when in the direction of propagation of the light. Then, for this case

$$-\frac{1}{u}+\frac{1}{v}=-\frac{1}{f}$$

$$\frac{u}{v}=\frac{A}{a}$$

$$u=-f\left\{\frac{A}{a}-1\right\}$$

$$v=-f\left\{1-\frac{a}{A}\right\}$$

$$L=F-u+v$$

Thus, in the instrument which Mr. BROWN used

$$A=6^\circ$$

and I wished to make $A=2^\circ$; moreover,

$$F=11\tfrac{3}{4}\text{ inches};\quad -f=2\text{ inches}.$$

These constants substituted gave

$$u=-4\text{ inches};\quad v=-1\tfrac{1}{3}\text{ inches};\quad L=14\tfrac{5}{12}\text{ inches},$$

and the brightness of the spectrum, with a slit of the same angular width, was three times what it would have been without the additional lens. It is evident that the apparatus admits of large variation: for example, had I chosen

$$\frac{A}{a}=4$$

then I should have had

$$u=-6\text{ inches};\quad v=-1\tfrac{1}{2}\text{ inches};\quad L=16\tfrac{1}{4}\text{ inches},$$

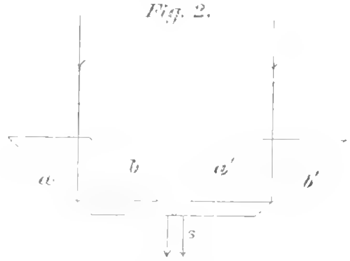
and the brightness would have been increased four times. I should have preferred the latter proportions had the tubing at our disposal admitted.

4. *Grating spectroscope.*—This was attached to my own equatorial, of 4 inches aperture, and contained a grating by ROWLAND of about 15,000 lines and an effective aperture of nearly 1 inch. The apparatus was used by Mr. C. H. ROCKWELL. There was also a flint-glass prism which could replace the grating, but it was not used during totality.

5. *Prism spectroscope.*—This was used in conjunction with Mr. ROCKWELL'S 6¼-inch equatorial by the writer. The objective of the equatorial has a focal length of 91 inches. The objectives of the collimator and viewing telescope have focal lengths of 12.8 inches and apertures of 1.6 inches, the available aperture of the single 60° flint-glass prism being also 1.6 inches. From the above dimensions it is evident that the effective aperture for central pencils was but 0.9 inch; but as the slit was made nearly an inch in length, and used radially, this was as much as could be employed under the condition that the whole pencil from nearly every portion of the slit should be transmitted. The magnifying power was 8, this yielding the maximum brilliancy under the assumption that the diameter of the pupil was $\frac{1}{9}$ of an inch. Of course it was better to have the ocular pencils small rather than too great. The eye-piece had an angular field of 52°, which admitted the whole spectrum within the field, while at the same timet he power was sufficient to show the D lines obviously separated.

The essential feature of the spectroscope, however, and that which adapted it to its particular purpose, was an arrangement of two total reflecting prisms just in front of the collimator slit. The office of these prisms was to form two virtual images, each being that of one-half the slit, separated at their nearest ends by an interval equivalent to the diameter of the solar image in the equatorial used. The construction will be rendered evident by the diagram (Fig 2), which represents a section of the apparatus by a plane passing through the slit and the line of collimation. The dimensions were so chosen that if light from the right side of the solar image were transmitted, after two reflections by the prism *a′ b′*, to the central point of the slit S, then light from the left edge of the solar image would be transmitted to S by the prism *a b*. It is evident that light from any other portion of the sun would not fall upon the lens of the collimator, and consequently not appear in the spectroscope, but that light from regions to the right and left of the sun, up to a distance determined by the length (in this case 15′) of the slit or the dimensions of the prism, would so appear; moreover, it is obvious that the spectra formed of the two halves of the slit would be adjacent. In fact, these two spectra, one that of the region to the right of the sun and the other that of the region to the left, were separated by a narrow black line about as distinct as the C line of the spectrum. Although all angles of reflection in the prisms were greater than the critical angle, the sides *a*, *b*, *a′*, and *b′* were silvered, to avoid trouble in keeping them clean.

*Fig. 2.*




It will be recognized that this spectroscope, which was specially devised for the work in view, was most carefully considered in all points so as to be of the highest efficiency. Nor do I see now, after having used it, how it could be bettered if the same large scale of 1.6 inches available aperture were not to be surpassed.

## OBSERVATIONS.

The observations made with all the instruments described, except the last, are given in the individual reports of the observers. Here I shall give my own only, though I shall have occasion to discuss some of the others.

A few minutes before the first contact the spectroscope slit was adjusted for parallelism with the utmost care, since the essence of the method was the comparison of two spectra formed by different halves of the slit. An ideally more perfect way of eliminating errors due to the slit would be to rotate the spectroscope by 180° on the axis of collimation of the equatorial at each observation, but as I found no difficulty in so adjusting that it was quite impossible to distinguish a difference in the two halves of the spectrum with any useful slit-width, I definitively abandoned the inconvenient reversals. After this adjustment the slit was given the maximum width compatible with sharp definition; that is, the spectrum was made as bright as possible under the limitation that the line D should be just recognizable as double. The group *b* was of course under these conditions, triple. It was expected that it would be unnecessary to alter this adjustment during the eclipse, and it was so found.

A short time before second contact the spectroscope was rotated on the axis of its collimator until the direction of its slit became sensibly normal to the edge of the solar image at the point of second tangency. As I was engaged in this way I noticed on the white card-board which covered the slit-plate a sudden alteration in the aspect of the image by the growth of arcs of light from the cusps of the sun, which quickly joined and formed a complete ring. The phenomenon occurred, as I found from Mr. FLETCHER's counting, 71 seconds before totality. It is only of scien.

tific importance as showing that the corona could have been seen much earlier by employing a more delicate method.

Just before second contact I put my eye to the spectroscope. The right-hand side of the spectrum, corresponding to the eastern limb of the sun, exhibited a long brilliant line in the place of 1474, extending 10′ or 12′ from the edge of the sun; on the other half, however, the line was much fainter and not more than 3′ or 4′ in length. The magnitude of the difference was so great a surprise to me that, although the appearance of the spectrum itself would have betrayed any fault in adjustment, I immediately tested it by giving the equatorial a slight motion east and west. The effect was what I anticipated—the shortening of alternately one and the other at the base, but no other change.

I had intended to examine all parts of the corona by rotating the spectroscope gradually through 180° on the axis of collimation, but the phenomenon observed was so important that I at once resolved to leave the spectroscope unchanged and to note the changes due to the moon's motion alone.

This exaggerated difference on the opposite sides of the sun lasted but a short time. I observed the rapid equalization, but only made the single entry in my note-book of equality at 200 seconds after beginning of totality.

Just at the beginning of totality I had seen the lines C, $D_3$, F, and near G extremely brilliant, but very short. This was, of course, just at the middle of my spectrum band, along a line extending from red to violet, and they were confined to that side of the line corresponding to the eastern limb of the sun. It is possible that some or all of these lines extended away from the middle of the band as very faint bright lines, but I could not be sure of the fact after the eclipse from a recollection of the hasty examination which I gave it.

At 200 seconds from the beginning, experience had shown that all the significant changes could be looked for only in the last few seconds of totality, and, as more than two minutes remained, I set myself to a deliberate examination of the spectrum of the corona exclusive of 1474.

That which first struck me was the intensity of the colors: none were too feeble to give a vivid impression of their hues, except perhaps the upper violet, which I fail to remember. Not less striking was the marked difference between this spectrum and one equally brilliant of sky-light. Two lines only were seen, the bright 1474 and the *dark* D line, rather faint. The latter, however, was so distinct that it could hardly have been regarded as a single line even if unfamiliar; but the other familiar groups, C, E, *b*, F, and less certainly G as being much fainter, were wanting. A streakiness at first suspected in the green was not rendered more probable by subsequent inspection. This observation was made with the utmost care and deliberation, as I was aware that it differed from the spectroscopic results reported at some former eclipses. I also made a single estimate of the extent to which the coronal line could be traced from the limb of the moon, and found it about 15 minutes of arc.

As the end of totality approached I again turned my attention to the 1474 line. At 280 seconds I recorded the line on the left side of the spectrum brighter and on the right side shorter, that is, the line had now become longer and brighter on the western side. This difference increased until returning sunlight put an end to the observations. At a time *estimated* as 20 seconds after Mr. Fletcher ceased counting, that is, at 320 seconds from the beginning of totality, I noted C, $D_3$, and F as appearing but very short. I cannot recall seeing the hydrogen line near G.

The conclusions to be derived from these observations are interesting. It is obvious that the enormous change in the extent to which the 1474 line could be traced east and west of the sun, with very slight change of the moon's place, at once precludes the explanation hitherto accepted of a gaseous atmosphere extending as far as implied by the spectroscope. On the other hand, we can find no explanation in diffusion by our own atmosphere, for diffusion was absolutely insensible. Still, as an eminent authority has suggested that this might be an adequate explanation of the phenomenon, it is well for me to give categorically the reasons for rejecting it.

*First.* The sky was extremely clear, and the moon during the eclipse sensibly black. Of course, if there had been any considerable diffusion, the moon would have looked less dark near the limb.

*Second.* The bright lines of the chromosphere and corona stopped abruptly at the moon's limb, although the diffusion here should have been more sensible than towards the outer corona, because at the place where the change in illumination was most rapid. It will be recognized that my examination of this point was a careful one, for by it I assured myself of the adjustment of the apparatus in the beginning of the observations.

*Third.* All the photographs taken by the English and French observers showed a sensibly black moon.

*Fourth.* In a photograph of the coronal lines H and K, taken by the English observers, these lines ended abruptly at the moon's edge, although the instrumental diffusion must have been much greater than in my own apparatus because they made use of a heliostat.

Before attempting any explanation of the observed phenomenon, however, it is well to review briefly all that study has taught us concerning the corona, for it is evident that no theory is tenable which is contradicted by any established fact. In this review I shall depend implicitly upon RANYARD'S "Observations made during total solar eclipses," which forms Vol. XLI of the Memoirs of the Royal Astronomical Society, and my references will be to the pages of that work. This admirable work, for which students of solar physics owe Mr. RANYARD a debt of gratitude, includes all useful observations to the eclipse of 1875 inclusive. For those of later date I shall refer to the original publications.

### *GENERAL REVIEW OF THE RESULTS OF OBSERVATIONS ON THE CORONA.*

### I.—SPECTROSCOPIC OBSERVATIONS.

As we shall find much contradictory evidence in these observations, and many cases of negative evidence even on occasions when definite advances in our knowledge have been made, it is necessary in a general discussion to establish some criterion by which this evidence may be weighted. Unquestionably the best method of determining the relative values of the observations is from the efficiency of the apparatus used in each case. To do this we must first discuss the theory of the spectroscope as applied to such work. This step seems to me advisable, not alone on account of the reason given, but also because the apparatus used is often so badly devised that the theory is evidently not generally known. The frequent description of non-essential constants of the spectroscopes used when the essential ones are omitted is another proof of inadequate apprehension of the optical principles involved.

Of the three forms of spectroscope used in corona observations we will discuss, in order, (*a*) the prismatic telescope; (*b*) the integrating spectroscope; (*c*) the analyzing spectroscope.

(*a*) *Prismatic telescope.*—This consists of a system of prisms or a grating before the objective of a telescope or the naked eye. The office of the dispersive system is to form a virtual spectrum of the corona at an infinite distance. This image is to be observed by means of the telescope. It is clear that a high magnifying power is not requisite for observing the coronal ring, since it measures a half degree in its inside diameter; on the other hand, it is equally evident that the image should appear as brilliant as possible. This last condition limits the magnifying power. According to the well-known law governing telescopic vision of a surface, the power for maximum brightness should be equivalent to the quotient obtained by dividing the diameter of the object-glass by the diameter of the pupil of the eye. If we assume the diameter of the pupil at $\frac{1}{8}$ of an inch, which cannot be far from the truth unless special precautions have been taken to dilate it, we should choose a power equal to eight times the numerical value of the available aperture in inches. If the coronal light contains an excess of definite wave-lengths, the fact will be indicated by colored images of the corona arranged according to their wave-lengths upon an impure spectrum as a background. It is well known that such rings are ordinarily seen corresponding in place to the lines C, $D_3$, 1474K, and F. With a dispersive power less than that of a 60° flint-glass prism they overlap; with a much greater power they are distinct rings. With a high dispersive power, also, the contrast between the rings and the background is increased, at least until the absolute loss of light incident to all highly dispersive apparatus becomes considerable. It is very important to observe, however, that the C ring alone is free from admixture with light of other refrangibilities, and that only on the side farthest removed from the blue end of the spectrum. On the other hand, the green ring, the 1474K, is least favorably situated for distinctness. We must expect, therefore, to find in such an instrument the C ring relatively much too strong. This peculiarity evidently makes the instrument a defective one for observing the corona; but the defect is partly balanced by its showing large surfaces instead of narrow spectral lines, thus enabling the observer to sometimes recognize the presence of light of definite wave-lengths, which the ordinary spectroscope would fail to reveal. There are a number of cases on record where just this advantage has been rendered evident.

(*b*) *Integrating spectroscope.*—This term has been applied to that form of instrument where the spectrum is that of the sum of all the sources from which rays passing through the slit fall upon any point of the effective aperture. Bearing in mind that the effective aperture is determined by the angular dimensions of the source of light, as well as by the linear aperture and focal length of the collimator, the theory does not differ from that of the analyzing spectroscope. The proper ratio of focal length to aperture has been discussed in the description of the instrument used by Ensign Brown. From what I shall prove in the theory of the remaining form of spectroscope, it follows that an integrating spectroscope with large available aperture is far superior for this particular purpose to one with equivalent dispersive power and smaller lenses.

(*c*) *Analyzing spectroscope.*—This differs from the instrument just described only in having an additional lens, which forms an image of the source of light upon the slit-plate. This lens is ordinarily called the "condensing lens." The term is objectionable, not only because it fails to define the function of the lens, but because it is misleading. For example, if we may speak of the "condensing" power of a lens, it is evidently a measure of the brightness of the image formed by it, and this depends solely upon the angular aperture of the lens. Now, I shall show that the brightness of the spectrum in the instrument under discussion is absolutely independent of the angular aperture of the "condensing lens." It follows, then, that the use of the lens is not to "condense" light upon the slit. It seems that a much better name for this lens is one which describes its office at once, namely, "image lens." This name I shall venture to use to replace the old term in the following discussion:

Let A = effective aperture of image lens.

F = focal length of image lens.

$a$ = effective aperture of collimating lens.

$f$ = focal length of collimating lens.

$d$ = diameter of pupil of eye.

$q$ = quantity of light incident on unit surface of image lens from one minute square of source.

We see at once that

$$\frac{A}{F}=\frac{a}{f};$$

for if this is not so, either some portions of the image lens can never send light to any portion of the collimating lens, or some parts of the latter never receive light from the image lens; in such cases either A or $a$ ceases to be the *effective* aperture.

The quantity of light (Q) falling on a minute square of slit, measured from the image lens, is evidently,

$$Q=\tfrac{1}{4}\pi A^2 q.$$

To find the quantity falling on a unit surface of the slit we must divide Q by the value of a minute square expressed in area. If we denote this quantity by Q′ we may write

$$Q'=\frac{Q}{F^2}=\tfrac{1}{4}\pi\frac{A^2}{F^2}q.$$

The function of the collimating lens is to form a distant vertical image of the slit. The brightness of this image may be expressed in the same way as that which we have chosen to express the brightness of the source, namely, by the quantity of light from a minute square of its area falling upon a unit surface. Let us denote this quantity, which is a measure of the brightness of the image, by $q'$. Now, we have already obtained an expression for the total quantity of light, Q′, falling upon the whole of the collimating lens from a unit area of the slit. To find $q'$, then, we have only to divide Q′ by the area of the collimating lens and by the value of a unit area of the slit expressed in minutes square. The first of these divisions is $\frac{1}{4}\pi a^2$, the second is $\frac{1}{f^2}$, whence

$$q'=\frac{Q'}{\frac{1}{4}\pi a^2}f^2=\frac{A^2 f^2}{F^2 a^2}q=q;$$

that is to say, the brightness of the image is the same as that of the source, and this perfectly independently of the apertures of the system used.

We may arrive at the same conclusion, by a process of *reductio ad absurdum*, very briefly, thus: Suppose $q'$ less than $q$, then, since there are no limitations as to the values of F and $f$, we may make them infinite without change of angular apertures. In this case we have reduced the quantity of light by introducing media which are assumed to have no action on light, which is absurd. Again, suppose $q'$ greater than $q$, then we have simply to regard the image as the source of light in a similar apparatus in which the image will be brighter than $q'$. Thus, by successive repetitions, we may increase the brightness indefinitely—an evident absurdity.

Hitherto we have not regarded the portions of the spectroscope which follow the collimator. Of these the system of prisms or the grating forms a virtual spectrum of the slit at the same distance (*i. e.*, infinite distance) from the collimating lens as the image itself, since only plane surfaces are concerned in the action. In order to determine the brightness of the spectrum we have here to distinguish between two cases. We assume, as we have tacitly done heretofore, that there is no loss either by reflection or absorption. Then, if the light is strictly monochromatic, or is composed of determinate wavelengths, the brightness of the spectrum depends solely upon the brightness of the image of the slit. In the second case the light is such as to yield a continuous spectrum. Then its brightness is proportional to the brightness of the slit-image and to the width of the slit, and inversely proportional to the angular dispersion of the prism or its substitute.

The function of the telescope is simply to aid in observing the virtual spectrum, and the laws governing the apparent brightness as seen through the telescope are the familiar laws of telescopic vision. With any magnifying power ($p$) from 0 to $\frac{a}{d}$ the brightness is invariable; and if we set $\frac{a}{d} = P$, the brightness for powers greater than P is proportional to $\frac{P^2}{p^2}$. Evidently the cases of $p$ between 0 and 1 correspond to an inverted telescope and $p = 1$ to naked eye vision.

But the mere brightness of a surface does not alone determine its visibility; it must not be too small, or, in the case of spectral lines, too narrow. The apparent width of a line is determined by the width of the slit and the magnifying power of the telescope. If the spectrum consists only of bright lines it is a matter of perfect indifference whether the necessary width is secured in one way or the other provided that their separation is sufficient. In the case of such a spectrum as that of the corona—and it is that which interests us here—the conditions are different. If the slit be widened, the continuous spectrum, upon which the bright lines are projected, is brightened so that the contrast is lessened. Hence we must, if we choose to secure sufficient width for the lines by this method, use more powerfully dispersive apparatus to assure contrast. With greater power in the telescope, which implies a greater value for the aperture, it is not necessary to use a wide slit, and consequently fewer prisms may be used. The relation of the two methods for securing the same result may be perfectly definitely stated. If the observing telescope always has the power expressed by the quotient obtained by dividing its aperture by the diameter of the pupil, then $n$ prisms with aperture $a$ is exactly equivalent to one prism with aperture $na$ as regards contrast between bright lines, of the same apparent width in each case, and their background.

This, however, is not all that we demand in a spectroscope for observing the corona. There are dark lines in the spectrum the width of which does not depend upon the width of the slit, consequently their visability does not depend upon the laws which we have just considered. In order to render such lines visible with any dispersive power the slit must have a very moderate angular width, hence with a small aperture it might be impossible to have the slit wide enough to show the bright lines and at the same time the dark ones. Suppose, for example, that the bright lines are so faint that in order to be distinctly visible they must not be less than 10′ in width. If no telescope were used with the prisms, a form which has often been employed, this would render all but the strongest lines of the solar spectrum invisible; if on the other hand a dispersive member of a tenth of the power but tenfold the aperture the same apparent spectrum would be obtained with a slit 1′ in width. This admits of a sharply defined spectrum. That a considerable angular width in the bands, with the exception of 1474 K, is requisite, has been proved in many observations of past eclipses, as well as in my own observations. In the latter, bands corresponding to C, $D_3$, and F were not seen, although Mr. UPTON's observations prove that they were present. Since they were carefully looked for and must have been as intrinsically brilliant as in the prismatic telescope, the only explanation is the wholly sufficient one of too narrow a slit. Had it been wider, however, the more important observations as regards dark lines would have been unsatisfactory. We see from these last considerations that for corona observations a spectroscope of large aperture is far superior to one of small aperture which would be regarded as equivalent to it by the rule in the preceding paragraph.

The principles developed above will be valuable to us in explaining the apparently contradictory evidence on record as to the spectroscopic nature of the corona. They can only be regarded as novel in so far as they direct attention to the fact that the conditions which must be satisfied in an apparatus designed for this particular use differ from those governing other spetroscopic observations; nor should I venture to give them here were there not most positive proof that they are not universally understood. Not only have some eminent authorities mistakenly laid stress upon the value of large angular aperture in the image lens, in their published programmes for eclipse observations, but guided by this erroneous theory they have too often failed to make the most of rare opportunities. This is a misfortune which would correct itself in time, but, unfortunately, the time for such observations is restricted. Moreover, the results derived from elaborate apparatus, even if based upon false theory, are apt to have undue weight accorded to them.

In our examination of the existing spectroscopic evidence relating to the corona we may group the observations, first, according to the date of the eclipse to which they pertain, and secondly, according to the character of the instrument used, taking in order the prismatic telescope, integrating spectroscope, and analyzing telescope.

1868.

Of the four observers who directed their attention to the spectrum of the corona not one gives the essential elements of the apparatus used.

RHIA used a "Bunsen's spectral apparatus of the simplest construction" with a single prism. The magnifying power of 20 was certainly far too high. Only a continuous spectrum was recognized; but the observer was confident that he would have seen dark lines in a solar spectrum of the same brightness.

TENNANT'S spectroscope is described as having a collimator of "short focus and considerable aperture." As his image lens had a focus of 5 feet and an aperture of 4.6 inches, the effective aperture of his spectroscope was probably very small. The dispersion was produced by a single prism. Faint continuous spectrum observed.

POGSON observed faint continuous spectrum. Instrument not described.

RAYET gives us sufficient data to enable us to make a fairly probable guess as to the dimensions of his spectroscope. For an image lens he used a reflecting telescope. His spectroscope was a direct-vision instrument 40 cm. in length with collimator lens so calculated as to receive all the light transmitted by the slit. If we suppose the reflecting telescope had an angular aperture of about $\frac{1}{12}$ this would imply an effective aperture of not far from $\frac{1}{2}$ inch. As the direct-vision prism probably had as large a dispersive power as two ordinary 60° prisms, we must conclude that Rayet employed a very efficacious instrument. He observed three bright lines in the corona spectrum which were doubtless $D_3$ 1474 K and F.

1869.

PICKERING used an integrating spectroscope with angular aperture of 7°. Two bright lines were seen, one near C and the other near E.

HARKNESS gives the constants of his apparatus with great exactness, and, as he failed to get the spectrum of the corona at first, but *after widening the slit* saw the coronal line with sufficient distinctness to determine its position on the illuminated scale, his experience affords a valuable guide in interpreting other records. According to his data the effective aperture of his single prism spectroscope was 0.45 inch with a magnifying power of 5.7. This failed to show anything of the corona spectrum with a slit-width which had been used in recording the spectra of three prominences. We may then fairly conclude that a spectroscope of less than $\frac{1}{2}$ inch effective aperture is ill suited for such observations.

YOUNG used an analyzing spectroscope with an effective aperture of $\frac{3}{10}$ of an inch and a magnifying power of 18; but as it had five 45° prisms it was a very effective apparatus for *bright* lines. With it he determined with great accuracy the position of the bright coronal green line. No dark lines were seen though looked for.

## 1870.

Of those observers who used integrating spectroscopes, HAMMOND (p. 424) saw a spectrum in which blue and violet were wanting, otherwise characterized by a red line—doubtless C. His instrument was a BROWNING's direct vision spectroscope, and therefore presumably without a telescope. In all probability the observer's eye was not in the proper place; at least such a supposition is the only plausible one which explains the anomalous observations. Of course, such an explanation is only tenable if the spectroscope was used without a telescope. ABBAY (p. 425) used a spectroscope with two 45° prisms and an effective aperture of not far from ½ inch, supposing the corona to have been ½° in breadth. He saw 1474 K and F during the whole of totality. PYE (p. 427) used a spectroscope of about ½ inch effective aperture (according to the assumption just made) with a 60° prism of dense glass. He observed, as did ABBAY, the lines C, $D_3$, 1474 K and F, but unlike that observer, he saw them during the whole duration of totality.

The remainder of the observers used integrating spectroscopes. BROWN (p. 419), BURTON (p. 437), DENZA (p. 438), LORENZONI (p. 444), and NOBILE (p. 445) give no data as to their instruments. The first named saw nothing: all of the others saw 1474 K.

CARPMEAL (p. 445). Spectroscope 60° prism with $\frac{3}{10}$ inch effective aperture: power 5. At first nothing was seen, but as the slit was widened three bright lines appeared. Clouds interfered with accurate determination of places.

MACLEAR (p. 420) does not describe his instrument. He saw five bright lines which he called C, D, E, *b* and F; these were also seen, less intense, on the body of the moon.

PERRY (p. 423) leaves undescribed the essential constants of his instrument, but as the Cassegrainian telescope which he used for an image lens had an angular aperture of only $1\frac{2}{3}$° it is highly probable that the effective aperture was too small for the moderately wide slit. He saw nothing.

WINLOCK (p. 430) employed a spectroscope with two prisms, otherwise not described. The observer recorded the positions of bright lines C, near D, 1474 K and F. He traced 1474 K to a distance of 25′ from the moon, and the others nearly as far. No dark lines were seen though the whole region above F was most critically examined.

YOUNG (p. 432). Instrument, a spectroscope with 13 prisms of 55°, with effective aperture a little less than ½ inch. The line 1474 K was traced from 10′ to 13′ from the sun; C and D to 4′ or 5′, and even on the disc of the moon. No dark lines were seen, though carefully looked for.

HARKNESS (p. 441) used the same apparatus which he had employed in 1869 with much the same result. 1474 K was estimated as extending 10′ to 15′ from the moon. Two less refrangible lines were suspected.

## 1871.

At this eclipse the "prismatic telescope" was first used. The two observers who made use of them employed widely different forms.

LOCKYER (p. 447) looked through five prisms of 45° each with the unassisted eye. He saw three hydrogen rings, together with a ring corresponding to 1474 K. The last-named was estimated as the least bright. All were regarded as of equal width, not more than 2′.

RESPIGHI's (p. 462) instrument had an aperture of 4½ inches, a single prism of about 13°, and a power of 40. He saw three rings corresponding to C, 1474 K, and F. Of these the second was the brightest and the last the faintest. The width of the green zone was estimated at 6′ or 7′.

Of those who used integrating spectroscopes SAXTON (p. 560) and TUPMAN (p. 469) both saw 1474 K and both fail to describe their apparatus.

FYERS (p. 467) observed with an integrating spectroscope of about $\frac{6}{10}$ of an inch aperture and a single 60° prism. The bright lines C, $D_3$, 1474 K, and F were seen.

FERGUSON (p. 470), with an apparatus similar to the last, saw the same lines as did FYERS, with four other faint ones, the positions of which were merely estimated.

The following observers employed analyzing spectroscopes:

LOCKYER (p. 446) with a 60° prism of $1\frac{1}{2}$ inches effective aperture saw a vivid hydrogen spectrum and the 1474 K line. He "was astonished at the vividness of the C line and of the continuous spectrum."

MACLEAR (p. 447) with a "6-prism spectroscope of great dispersive power" and a "7-prism direct-vision spectroscope," saw nothing whatever.

JASSEN (p. 450) fails to describe the essential constants of his apparatus, but emphasizes the fact that the image lens was of large angular aperture, thus, in the opinion of the observer, yielding exceptionally brilliant spectra. We may be permitted to discuss this apparatus somewhat minutely, not only as a good illustration of the theory given above, but on account of the importance of the observations made with it.

A silvered mirror of 15 inches aperture and 60 inches focus was used as an "image lens." The dispersive member consisted of two direct-visionprisms. No telescope was used.* Nothing is said about the aperture of the collimator and prisms except that they were so constructed as to transmit the whole pencil from the mirror. Let us suppose the collimator 4 inches in length, which would correspond to an effective aperture of 1 inch. Then we should have a beam of light 1 inch in diameter from the prisms, but only that portion falls upon the retina which can pass through the pupillar aperture. If we suppose the diameter of the pupil to be $\frac{1}{8}$ of an inch, then all the light which reaches the retina comes from a portion of the image mirror 2 inches in diameter, and the remainder is useless. Again, since such prisms are usually equivalent to two or three prisms of 60°, we see that the apparatus is inferior to a single-prism spectroscope of $\frac{3}{4}$ of an inch effective aperture even for observing bright lines; and, in accordance with the principles explained in the theory of the instrument, it is greatly inferior to such a single-prism spectroscope for detecting dark lines. It is clear that any other assumption as regards the focal length of the collimator would not affect the conclusion; for, suppose the length twice as great, then, since the effective aperture of $\frac{1}{8}$ inch is not altered, only one-fourth as much of the mirror would be utilized; but, at the same time, a slit of the same angular dimensions would have four times the area; thus an exact compensation would result.†

The observer saw the hydrogen lines bright, as well as 1474 K. Besides these, D was seen as a *dark* line, with some faint ones in the green. The bright lines were traced to a distance of 10′ to 12′ from the limb of the moon.

HERSCHEL and TENNANT (p. 454) give no description of the spectroscope used. They saw 1474 K only, and saw it at a distance of 8′ from the moon.

MOSELEY (p. 471). Captain TUPMAN describes the spectroscope used as having a collimator 5 inches focal length, 0.7 inch aperture, with a direct-vision prism of 2 flint and 3 crown prisms. The image lens was of $3\frac{1}{2}$ inches aperture and 33 inches focus. "Power of the whole combination about 40." This gives effective aperture of 0.53 inch and magnifying power of 6. This should

* This fact was overlooked by Mr. RANYARD in his discussion of the same instrument.

† Mr. RANYARD, at p. 451, calls attention to M. JANSSEN's fallacious reasoning in a foot-note. As, however, he not only concludes that this special apparatus was after all very efficacious, but also computes the "intensity of the image" (pp. 375–378) for all the instruments used, we are driven to the conclusion that he overlooked the full force of his logic. In this connection his remarks on p. 375 are very instructive.

have been a very effective apparatus had the telescope instead of the slit been movable; but, as the observer tells us that with his adjustment "the center of the slit was far from coinciding with the axis of the telescope," the effective aperture may have been much less. He saw 1474 K and traced it to a distance of 22′ ± 5′ from the moon's limb.

1874.

STONE (p. 475). It is especially to be regretted that this observer fails to give the constants of his instrument, not only on account of the value of his observations, but because he was the only spectroscopic observer of this eclipse. He saw the hydrogen spectrum with 1474 K bright on a continuous spectrum in the inner corona, and traced the last-named line in the outer corona to a distance of more than 1° from the moon. He also detected dark lines in the spectrum of the outer corona, though they were seen with great difficulty.

1875.

Nothing of the spectroscopic nature of the corona was learned at this eclipse.

1878.

Professor BRACKETT (Amer. Jour. Sci., vol. xvi, p. 287) used a very efficient prismatic telescope, but failed to recognize other than a continuous spectrum of the corona. Other observers with prisms or gratings used without telescopes saw no more.

Mr. BENNET (Amer. Jour. Sci., vol. xvi, p. 287), with a very efficient integrating spectroscope saw 1474 K and F for a few seconds after the beginning of totality and again for a few seconds before its termination.

Professor BARKER (Proc. Amer. Ass. Adv. Sci., 1878, p. 113) used a direct-vision analyzing spectroscope, with telescope and collimator having 4-inch focal lengths and $\frac{3}{8}$-inch apertures. The dispersive power was nearly equivalent to that of two 60° prisms. This instrument was attached to a 4-inch telescope by JONES, of London, not otherwise described. If we assume the ordinary ratio of aperture to focal length in the image lens, *i. e.*, $\frac{1}{15}$, we find that the effective aperture of the spectroscope was only about $\frac{1}{4}$ of an inch. No bright lines, but numerous dark lines were seen Of these, *b* and F were especially distinct,* and D, E, and G considerably less so. They were all fainter than in an ordinary solar spectrum of the same brightness.

Professor EASTMAN (U. S. N. Obs. Rep., 1878, p. 299) employed a single prism instrument with an effective aperture of 0.9 of an inch; power not stated. With a wide slit he traced 1474 K to a distance of from 10′ to 14′ from the moon's limb. No other lines were seen.

Professor HARKNESS (U. S. N. Obs. Rept., 1878) confined his attention to the ultra-violet region of the spectrum, where he failed to find any lines.

Commander SAMPSON (U. S. N. Obs. Rept., 1878, p. 113) does not give the essential constants of his instrument. Using a narrow slit, the observer failed to see either bright or dark lines in the continuous spectrum exhibited.

Professor YOUNG (Amer. Jour. Sci., vol. xvi, p. 285) employed a single-prism spectroscope with a fluorescent eye-piece. The field of view extended from about C to above F. C, $D_3$, 1474 K and F, were visible throughout totality. Of these, C was traced to a height of 10′ and F of 5′ from the moon's limb.

* It will be seen that Professsor YOUNG found F a *bright* coronal line throughout this eclipse.

SUMMARY OF SPECTROSCOPIC EVIDENCE.

This review, in which all the available spectroscopic evidence concerning the nature of the corona is collected, is most instructive. Leaving out of account the integrating spectroscopes, because they do not distinguish between the lines due to the corona alone and those which have their origin in chromospheric light, we find that not a single observer, who has made use of an instrument which by description is as efficient as a single-prism spectroscope of $\frac{3}{4}$-inch aperture, has failed to see the bright 1474 K line in the spectrum of the corona. As to the height to which this line could be traced, at no eclipse when the effort has been made has this been less than 25′ as a maximum except during that of 1878, when a single observer only (EASTMAN) attempted to find its limits; he found 14′ for a maximum.

The evidence of the existence of the hydrogen-spectrum in the coronal light is really not less conclusive. Ten of the fifteen observers who saw 1474K also saw the hydrogen lines. But what adds indefinitely to the strength of the evidence is the fact that all the observers who describe their apparatus as of greater efficiency than a single prism of $\frac{3}{4}$ inch aperture saw the bright hydrogen lines, with the exception of two. Of these two, one (YOUNG, in 1869) may have had too narrow a slit, as he was looking particularly for dark lines; the other (EASTMAN, 1878) was observing at a time when all the bright lines were exceptionally faint. The height to which the hydrogen lines have been traced varies from 5′ or 6′ up to nearly 25′. The line $D_3$ is to be classed with those of hydrogen.

All the evidence, some of it most decisive, goes to show that the distribution of the light which yields this line spectrum has no relation to the rifts and streamers which characterize the various coronas.

As to the presence of dark lines in the spectrum of the corona, the evidence is more conflicting. It is evident that the integrating spectroscope is, if properly designed, as well suited for the detection of such lines as the analyzing, but with the exception of BROWN, in 1883, who reported D as a dark line, no one has detected any with this form of instrument. With analyzing spectroscopes, JANSSEN, in 1871, saw D with some faint lines in the green, and the writer D alone in the recent eclipse. Besides these, a single observer (BARKER, in 1878) has reported all the prominent Fraunhofer lines as evident. On the other hand, many of the most experienced observers with the most efficient apparatus have failed to detect them, even when looking specially for them. The observations of Mr. STONE in 1874 are not included here, as they applied to the outer corona only. Whatever interpretation be placed upon the presence or total absence of dark lines, the conclusion is inevitable that the proportion of true solar light in that of the corona within 5′ or 6′ of the moon's limb is so small that all but the strongest of the Fraunhofer lines are invisible in any spectroscope which has hitherto been employed. Here we have a starting point from which we can, by means of experiment, determine the minimum limit of the ratio of sunlight in the corona. It is only necessary to mix light which yields a continuous spectrum with sunlight until we can secure a spectrum which resembles that of the corona.

This experiment I have tried in the following manner: Before the slit of the same spectroscope used at Caroline Island I placed a number of glass plates, varying from one to twelve, at an angle of 45°. In front of these was a screen of white paper upon which fell a beam of sunlight from a heliostat. A gas-flame was placed in such a position that a portion of its light was reflected into the collimator by the glass plates. Two small movable screens were so adjusted that, at will, one-half of the slit could receive sunlight alone, while the other half was illuminated by gas-light only, or, the whole slit could receive both kinds of light simultaneously. The quantity of sunlight which entered could be regulated by the opacity of the paper selected for the screen, and the quantity of gas-light by the number of glass plates used in the reflector before the slit.

1. By means of the movable screens it was easy to adjust the apparatus so that the quantity of light from the two sources should be sensibly equal; then, when the two small screens before the slit were removed, the spectrum was that of sunlight mixed with an equal quantity of light yielding a continuous spectrum. This was found to show in the central portion of the spectrum the lines D, E, *b*, F, and very many distinct but fainter lines in the green. This proves that in the corona less than half the light giving the continuous spectrum is reflected sunlight.

2. The relative quantity of light from the flame was successively increased. When two or three times as great as the proportion of sunlight the fainter lines disappeared and only those remained which are named above; then, still increasing the relative amount of gas-light, F, E, and D disappeared, leaving *b* distinctly visible long after. This can hardly excite surprise, for the *b* group is obviously the strongest line in a faint solar spectrum. But the necessary deduction from the experiment is a very important one. Since there was enough sunlight in the coronal spectrum to render visible the weaker line D while the *b* group was invisible, there must have been present an excess of light of the wave-lengths of the *b* group; in other words, if the corona had been deprived of all purely solar light the brightest of the magnesium lines would have been added to those of hydrogen and 1474K.

## II. POLARIZATION OF THE CORONAL LIGHT.

It is unnecessary to review the observations on this point with such minuteness as we have employed in discussion of the spectroscopic evidence. This is owing not only to the thorough manner in which Mr. RANYARD has done it, but also because there is no room for doubt, especially since Professor WRIGHT's admirable work at the eclipse of 1878, that the coronal light is strongly polarized *radially*. The intensity of polarization and its distribution with reference to the sun are, however, of the greatest theoretical importance. Thus all evidence bearing on these points deserves our critical examination. Unfortunately, there are few observations to guide us here, though some are of great value. There are certain observers who have given estimates of the percentage of polarization in the coronal light or of its variation in passing from the moon's limb outwards. They are PRAZMOWSKI (1860), LANGLEY (1870), BLASERNA (1870), and HASTINGS (1878). Mr. PRAZMOWSKI writes (p. 281), as nearly as I can recall, the portion of the corona most "strongly colored did not correspond to the most brilliant part, but was situated at a certain distance from the edge of the moon." This, as a mere recollection, and differing from all others who have used the same method (notably RANYARD, in 1871), has necessarily little weight.

Professor LANGLEY (U. S. Coast Survey Report, 1870, pp. 158–164) concluded that the polarization diminished near the moon's limb, because the bands in his Savart polariscope did extend to that limit. But from the peculiarity of the apparatus this conclusion does not follow. The bands were about 1° 50′ apart, while the apparent diameter of the moon was only 6° in his instrument, so that successive bands would fall on widely different regions of the corona. In short, even if the polarization had been 30 per cent. at the limb, the bands, other than the central one, would have faded out before reaching the limb.*

Professor BLASERNA, in the eclipse of 1870 (p. 309), estimated the strength of the polarization near the limb as equal to that of a clear sky at 50° from the sun. This corresponds to a percentage of about 30.

Dr. HASTINGS (U. S. Naval Obs. Report, 1878, p. 158), by an apparatus which did not admit of

*The theory of this instrument has been discussed more fully in the U. S. N. Report, 1878, p. 161, by the writer.

his knowing the portion of the corona under observation, found the polarization increasing up to the limb. That of the light from an area 3′ in diameter and close to the limb of the moon was estimated as not less than 30 per cent.

Two observers have made quantitative measurement, namely, Winter in 1871, and Wright in 1878.

Mr. G. K. WINTER (p. 324) found the percentage of polarization close to the limb 16; at a distance estimated as 10′ from the limb it was 25. The first of these numbers is a single observation, the second the mean of four.

Professor WRIGHT (U. S. N. Obs. Report, 1878, p. 270) found at points radially disposed on the corona, at the distances 6′, 12′, and 22′ from the limb of the moon, the corresponding percentages of polarization to be 12, 7, and a trace only. If this can be regarded as yielding the law of variation of polarization, it implies a high degree of polarization at the inner boundary of the corona.

The definite conclusion from these and other observations is that the coronal light is strongly polarized radially, and that the percentage of polarization increases continuously up to the limb of the moon, where it cannot be less than from one-fifth to one-third of the whole.

### III. PHOTOGRAPHY.

The photographic evidence as to the nature of the corona is extremely difficult to deal with, not merely because of the enormous changes in the aspect of the picture with change of duration of exposure, of sensitiveness of plates, and of angular aperture of camera, but because no two eclipses have been photographed in a like way as regards these variable quantities. We may, however, regard the following points as demonstrated by the method:

*First.* That there is no outer limit to the corona; in other words, that its extent in a photograph is only determined by the three elements above defined.

*Second.* That the structure of the corona is, generally speaking, radial.

*Third.* That "rifts" and "streamers," that is, dark regions and bright regions radially disposed, are not confined to the outer corona, but extend even to the limb of the moon.

*Fourth.* That photographs taken during the same eclipse resemble each other, but those belonging to different eclipses are very diverse.

### ACCEPTED EXPLANATION OF THE CORONA.

The accepted explanation of the corona has been supposed to account more or less satisfactorily for all the observed phenomena. It may be summarized briefly thus:

*a.* The sun is surrounded by an atmosphere of incandescent gas, chiefly of the material which yields the 1474K line, and of hydrogen extending to a height of not less than 600,000 miles above the photosphere and probably to more than 1,200,000 miles (STONE).

*b.* Mixed with this atmosphere, *i. e.*, suspended in it, falling into or projected from the sun, is a large quantity of solid or liquid material, which is at such a temperature as to be self-luminous. It is this which yields the continuous spectrum free from dark lines.

*c.* Besides these components of the envelope, there is present matter which reflects or diffuses light much as our own atmosphere does. To this is attributed the partial radial polarization of the corona.

*d.* The streamers and rifts in the corona indicate matter repelled, in various quantities, from the sun by forces which may be electrical.

This neglects no one of the established features of the corona and has apparently contented most writers. It is essentially the explanation given by Professor YOUNG in his work on *The Sun*, though he does not fail to note grave difficulties in the way of accepting it. When, however, we demand of the theory a quantitative agreement with observation, we find that it utterly breaks down. Some of the assumptions involved are so exceedingly improbable that we refuse to regard as plausible a hypothesis resting on them, while others equally as essential are absolutely negatived by the observations. We will consider these points in turn:

First (*a*). Since the spectroscope demonstrates that the gaseous pressure at the limit of the chromosphere is very small, probably far less than that of an inch of mercury, this supposition requires that the pressure of the assumed atmosphere from 600,000 to 1,200,000 miles deep shall be thus inconsiderable, notwithstanding that the force of gravity is more than twenty-seven times as great at the surface of the sun as at the surface of the earth. As improbable as this consideration renders the assumption of a gaseous atmosphere, we find a still stronger objection in the motion of comets. All optical evidence of the existence of our own atmosphere ceases at a height of about 45 miles; still, the density at more than twice that altitude is sufficient to offer a resistance to bodies moving with velocities averaging 1.4 times that of the earth in its orbit, such as to render them incandescent almost instantly. Now, the illumination of a particle in the corona is not indefinitely greater than that of one in our own atmosphere, the ratio being that of the angular area of the sun as measured from the two points. It follows, then, that the density of a visible atmosphere near the sun cannot be indefinitely less than that of our own at 45 miles from the earth. But we have the clearest evidence that far within the limits of the corona the density must be almost infinitely less than that of our atmosphere at even 60 miles above the earth's surface: for the great comet of the last year passed at a distance of 300,000 miles of the sun, hence deep within the assumed coronal atmosphere, for a space of several millions of miles and with a velocity 180 times that of the earth in its orbit, not only without being stopped and precipitated upon the surface of the sun, but without having been checked in the least. This was proved by the fact that the orbit derived from observations after perihelion passage was sensibly the same as that before. Still more conclusive proof is offered by the comet of 1843, since it passed still nearer the surface of the sun. It is true that its orbit before and after perihelion passage does not admit of such comparison as in the more recent case, but we are forbidden by every law of probability, just because of its small perihelion distance, to assume a higher velocity before nearest approach than that due to a parabolic orbit; this it had after leaving the neighborhood of the sun. We must not, in weighing this evidence, overlook the fact that the resistance offered by an atmosphere increases with enormous rapidity with increasing velocity of motion. Surely, no more decisive argument against the existence of an atmosphere extending as far as the perihelion distance of either of these comets could be imagined.

But the assumption of an extensive atmosphere leads to a contradiction to our experience wholly independently of such considerations which would render it untenable. According to theory, as well as observation, the upper limits of the gaseous envelopes of the sun ought to be ordered according to their densities. The material which produces the 1474 K line, and which may always be seen in the chromosphere spectrum, is, according to this criterion, as unmistakably denser than hydrogen as is magnesium vapor, or of iron vapor; but if we accept the coronal spectrum as evidence of the existence of an atmosphere, we are, by exactly the same principle, driven to the conclusion that the 1474 K material is far less dense than hydrogen. The contradiction could not be more abrupt and inexplicable.

There are two other arguments of not inconsiderable weight which are opposed to the supposition of a coronal atmosphere. First, the photographs indicate what may be styled a *flat* arrangement of the corona, as though the forces which produce its irregularities act only in a plane at right angles to the line of vision. That is to say, the rifts and streamers seem to have their origin at or near the limb of the sun and are often narrowly limited in width. Such a character might well exist if the corona were determined by the *disk* of the sun, but would be highly improbable if it were distributed about the solar globe; secondly, we are compelled by this theory to assume most improbable changes in the hypothetical atmosphere. For example, the line 1474 K was traced to a distance of 1,200,000 miles from the sun in 1871, while four years later it was so feeble as to have eluded all but two of the observers, notwithstanding that the conditions of vision were probably better then than ever before. If the line demonstrates the existence of an atmosphere, it demonstrates also inconceivable changes in it.

In regard to the matter (*b*) which emits the white light, our statements must be a little less positive. That it is not of solid or liquid particles suspended in an atmosphere after the nature of our clouds is pretty evident from the necessary rarity of such an atmosphere.* The supposition that a large quantity of meteoric matter is falling into the sun offers almost as great difficulties. We must conclude that it is falling nearly vertically downwards in the immediate neighborhood of the sun, because the necessary orbital velocities to check this precipitation could not exist within an atmosphere, even if we disregard the difficulties in the way of accepting a theory which implies a swarm of satellites whose orbital poles are distributed uniformly over the heavens; hence there must be a continuous supply from without. This supply cannot come from parabolic comets unless those of small perihelion distances are more abundant than those of great. I am not aware that there is any evidence, founded either on theory or observation, which cannot be explained by the greater brightness of comets near the sun, and hence their greater liability to discovery, for such a distribution of perihelion distances. It is true that such a law for periodic comets might be probable, but as these are likely to have the poles of their orbits near the poles of the ecliptic, they, although they serve admirably to explain the zodiacal light, could not give such a corona as we observe. Perhaps the assumption of an interplanetary resisting medium would help the hypothesis of a meteoric constitution, but it would be another hypothesis. The possibility of matter ejected from the sun we will consider with the structure of the corona.

The polarization (*c*), when considered quantitatively, is even more incompatible with the accepted theory than either of the phenomena previously discussed. It is clear, as has been pointed out by a number of writers, that the polarization of light reflected from a particle at the surface of the sun is *nil*, because the luminous source there is a surface with an angular subtense of 180°. It is also easy to see that therefore the polarization of the corona near the limb of the moon must be small, even if all the light is diffused by matter in such a state of subdivision as to give a maximum effect. At a greater distance from the moon the percentage of polarization should be greater. But this is quite contrary to the observed law. In 1878 I made a number of approximate calculations as to the percentages of polarization at various distances from the moon, and found them widely at variance with the estimated values in my own observations. In December, 1879, Dr. Schuster† published an elaborate analytical discussion of the problem. We will make use of the results of his investigation. These, under various assumptions as to the law of distribution of matter about the sun which should diffuse light so as to give the maximum amount of polarization, are given in the accompanying table:

* It is perhaps worth noting that whatever argument can be drawn from the independence of the viscosity of a gas or pressure and its increase with temperature cease to apply when the mean free path is large compared to the dimensions of the body considered.

† R. A. Soc. Month. Not., vol. 40, p. 36.

TABLE I.†

[$a = 38.73$.]

| $d$. | $r^0$. | $r^{-2}$. | $r^{-4}$. | $r^{-6}$. | $r^0 - r^{-2}$. | $r^{-2} - r^{-4}$. | $r^0 + ar^{-2}$. |
|---|---|---|---|---|---|---|---|
| ′ | | | | | | | |
| 0.00 | 11.1 | 12.9 | 12.0 | 10.9 | 9.1 | 16.4 | 12.9 |
| 0.44 | 12.1 | 14.8 | 14.1 | 13.3 | 9.4 | 16.7 | 14.6 |
| 0.56 | 13.9 | 18.3 | 18.5 | 18.0 | 10.1 | 18.1 | 18.1 |
| 1.31 | 16.3 | 22.9 | 24.0 | 24.1 | 11.7 | 21.0 | 22.5 |
| 2.18 | 18.9 | 28.2 | 30.5 | 31.3 | 14.0 | 25.3 | 27.5 |
| 4.18 | 21.7 | 33.8 | 37.4 | 39.1 | 16.8 | 30.5 | 32.7 |
| 6.6 | 24.3 | 39.5 | 44.6 | 47.1 | 20.0 | 36.5 | 37.9 |
| 10.3 | 26.7 | 44.9 | 51.6 | 55.0 | 23.3 | 42.6 | 42.6 |
| 16. | 29.0 | 49.9 | 58.1 | 62.5 | 26.5 | 48.1 | 45.9 |
| 26. | 30.8 | 54.3 | 63.7 | 69.1 | 29.1 | 52.9 | 47.2 |
| 46. | 32.3 | 57.4 | 67.8 | 72.6 | 31.5 | 56.8 | 45.4 |

† This is Table IV of the article cited, altered to give percentages and distances from the limb.

The first column, under $d$, gives the angular distance from the limb of the sun; the next, under $r^0$, gives the corresponding percentages of polarization for an atmosphere of unvarying density, while the other columns give the values for different laws of atmospheric density; *e. g.*, the fifth column contains the results of calculation under the assumption that the density decreases as the the sixth power of the distance from the sun's center. It will be seen that it makes little difference what laws of distribution be assumed for the neighborhood of the limb: the polarization is there feeble, not far from 12 per cent., and increases continuously outwards. Since we have seen, however, that not more than one-fourth or one-fifth of the light of the lower corona can be diffused sunlight, even eight times the polarization theoretically possible would not yield the percentage observed.

Again, the polarization must, if due to reflection by an atmosphere, increase continuously with increasing distance from the sun. That it does not do so is established beyond question. The only imaginable explanation for this is the admixture of increasing quantities of non-polarized light at higher altitudes, which, as we have just seen, cannot be admitted near the sun. But if we decline to accept any values for polarization other than those yielded by direct measurements, we have enough in Professor WRIGHT's observations of 1878 to demonstrate that the assumed explanation is untenable, notwithstanding that his measures did not come nearer than 6′ from the moon.

It is easy to calculate from the last table what must be the relative quantity of mixed light from other sources, in order to reduce the theoretical numbers to correspond with his observations. If we represent this quantity for any point in the corona by A, the quantity of diffused light for the same point being unity, then the values for A are given in the following table:

TABLE II.

| Law of density. | A, $d = 6'$. | A, $d = 12'$. | A, $d = 22'$. |
|---|---|---|---|
| $r^0$ ........ | .97 | 2.9 | 14.1 |
| $r^{-2}$ ........ | 2.2 | 5.6 | 25.3 |
| $r^{-4}$ ........ | 2.6 | 6.6 | 29.7 |
| $r^{-6}$ ........ | 2.8 | 7.2 | 32.3 |
| $r^0 - r^{-2}$ ........ | 0.6 | 2.5 | 13.1 |
| $r^{-2} - r^{-4}$ ........ | 1.9 | 5.3 | 24.5 |
| $r^2 + ar^{-2}$ ........ | 2.1 | 5.2 | 22.4 |

Here Professor WRIGHT's "trace" at 22′ is assumed to be equal to 0.02.

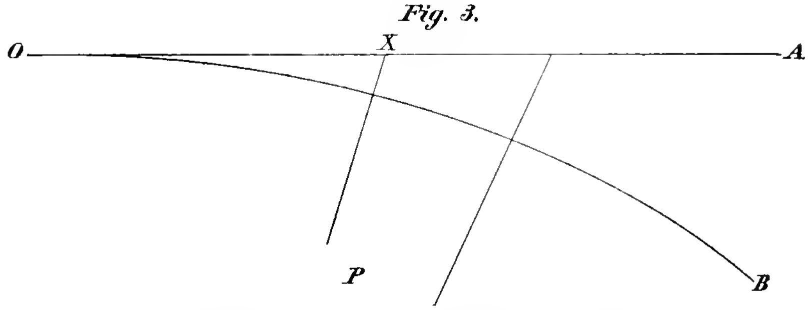
We are forbidden to assume that this undiffused A is reflected by particles too large to produce polarization, for the coronal spectrum would, in every case, exhibit the Fraunhofer lines, and in all but two cases be practically indistinguishable from a solar spectrum of the same brightness. The only supposition left is the wholly improbable one that the relative proportion of incandescent matter increases in a very rapid ratio with increasing distance from the sun.

The final assumption (*d*) that the coronal streamers are formed by matter repelled from the sun is objectionable on account of what it implies. Since the rifts are often many times darker than the streamers, it follows that nearly *all* the white light comes from such ejected matter. Moreover, since the material does not give the solar spectrum, it is not bright because illuminated by the sun, but is self-luminous. We have already alluded to the extraordinary arrangement of the streamers, as though confined to a plane at right angles to the line of vision.

PROPOSED EXPLANATION.

Such objections as have just been considered led the writer, after the eclipse of 1878, to seek for a hypothesis free from the obvious defects of the old one. That the origin might possibly be found in the phenomenon of diffraction was an idea early suggested, though it is not at first apparent that such an explanation could eliminate the difficulties connected with the polarization of the corona. On the other hand, the most elementary considerations of the theory of diffraction show that in the case of a total eclipse we should see a ring of light around the moon, brightest on the inner side and extending indefinitely outwards; moreover, that the light of this ring would be derived exclusively from areas very near the limb of the sun. That there would be no maxima and minima of brightness in such a ring, either in place or time, follows from the well-known fact that within the geometrical shadow such periodic variations are absent. Notwithstanding these features, so strongly suggestive of the true corona, a quantitative application of the theory of diffraction would seem to render the hypothesis untenable. We may test the validity of the hypothesis thus:

*Fig. 3.*




Let OA be the line of intersection of a plane, passing a point $p$ on the surface of the earth within the geometrical shadow of the moon and the center of the sun, with a wave surface having its origin in the sun. Also let OB be the intersection, by the same plane, with a spherical surface having its center at $p$ and tangent to OA at O, with a radius equal to the moon's distance. It is required to find an expression for the illumination at $p$ due to any point on that solar diameter defined by the plane OA $p$. This is the well-known problem solved by Fresnel. Obviously, for the purpose of investigating the distribution merely, we may consider OA a right line. We will define the position of a point $x$ on this line by its distance from O.

The velocity of motion produced in a particle of luminiferous ether at $p$ by an element $dx$ of the wave surface at O is, with proper choice of the origin of time, proportional to

$$dx \sin 2\pi \frac{t}{\mathrm{P}},$$

while P is the period of vibration. For any other element of OA a velocity is imparted which bears the same ratio to

$$dx \sin 2\pi \left\{ \frac{t}{P} - \frac{\delta}{\lambda} \right\},$$

where $\delta$ is the difference of the distances of the two elements considered from $p$. If the distance $Op$ is represented by R, $\delta$ is evidently equal to $\frac{x^2}{2R}$. The total velocity given to the particle at $p$ will equal the sum of the velocities due to each element, whence we may write for the portion included between $x'$ and $x''$,

$$v \propto \int_{x'}^{x''} \sin 2\pi \left\{ \frac{t}{P} - \frac{x^2}{2R\lambda} \right\} dx$$

This developed gives

$$v \propto \sin 2\pi \frac{t}{P} \int_{x'}^{x''} \cos 2\pi \frac{x^2}{2R\lambda} dx - \cos 2\pi \frac{t}{P} \int_{x'}^{x''} \sin 2\pi \frac{x^2}{2R\lambda} dx$$

The intensity of illumination at $p$ is proportional to the quantity of energy transmitted to it in a given time, and this is obviously proportional to the mean square of $v$, but since the mean value of $\sin 2\pi \frac{t}{P} \cos 2\pi \frac{t}{P}$ is zero, while that of $\sin^2 2\pi \frac{t}{P}$ is a constant equal to that of $\cos^2 2\pi \frac{t}{P}$, we find for an expression for the intensity

$$I = k \left\{ \left[ \int_{x'}^{x''} \cos \pi \frac{x^2}{R\lambda} dx \right]^2 + \left[ \int_{x'}^{x''} \sin \pi \frac{x^2}{R\lambda} dx \right]^2 \right\}$$

In calculating the quantity of light due to any point on the sun, we must extend the integration from a value of $x'$ corresponding to the limit of the moon up to infinity. But if the value of $x'$ be but a few times greater than $\sqrt{\frac{R\lambda}{2}}$ the value of I becomes indefinitely small. The relation of $x'$ to the apparent angular distance from the moon's limb is, if we represent this angle by $\alpha$, given by the equation

$$\alpha = \frac{x}{R}$$

whence we conclude that in order that any portion of the sun's surface may give a sensible amount of light to $p$, its angular distance from the moon's limb shall be not many times greater than $\sqrt{\frac{\lambda}{2R}}$; in other words, the distance within the geometrical shadow of the moon, where light due to diffraction may be found, is limited to inches rather than miles. Thus it would appear that the corona can have no explanation founded upon this phenomenon of light; and, indeed, there would be no escaping the conclusion if the suppositions at the base of the argument are correct. But, in setting the phase of vibration equal $\frac{x^2}{2R\lambda}$, we have tacitly assumed that the motions in the different wave-surfaces are strictly similar; this is not the case, for we know that two surfaces differing by a few tens of thousands of wave-periods in their origin are wholly incapable of producing phenomena of interference. For example, we can secure Newton's rings with proper precautions as to the homogeneity of the light with a difference of path of half an inch, but no phenomenon of the kind can possibly be discovered if the difference is as great as 2 inches. Accordingly we can only find the value of I by taking the mean value of

$$\left[ \int_{x'} \sin 2\pi \left( \frac{t}{P} - \frac{f(x, t)}{\lambda} \right) dx \right]^2$$

where $\frac{f(x, t)}{\lambda}$ represents the phase. Of the nature of this function we know little except in every practical case it is a continuous, non-periodic function of the time, and that its value must depend upon the physical characteristics and temperature of the source. For integrations which involve very small changes in the value of the function, or in which it may be regarded as independent of $t$, FRESNEL'S solution is accurate, but in cases where R is very great it fails.

With our limited knowledge of the nature of $f(x, t)$ it is perhaps hopeless to attempt by analytical methods alone to find the illumination within the geometrical shadow; but it is easy to see that much more light would fall there than would be the case if FRESNEL'S solution obtained, for it is the assumed perfect regularity of the phenomenon which causes the integrals to vanish when the lower limit is considerable. Nothing remains then but an appeal to experiment. This was done by employing a lens system of 5 inches diameter, with a lime light in the more distant principal focus as an artificial sun. It is evident that near the axis of the system this would appear as an intensely brilliant disk, and, at a distance of 50 feet, of about $\frac{1}{2}$ degree in diameter. This was hidden to the eye by a blackened metal disk, 1 inch in diameter, placed at such a distance as to be slightly greater in angular diameter. It was suspended by three fine wires at the center of a ring for support. Under these circumstances the black disk was seen surrounded by a vivid ring of light, even when of considerably greater diameter than the artificial sun. This ring was of intense brilliancy next the disk and faded rapidly outwards. Its height was from 10′ to 30′ and, as a whole, had a most striking resemblance to the solar corona except in its great regularity. That most of the light was derived from the edge of the luminous disk was proved by the effect of stopping off the center of the lens. This was done by an assistant, and it was found impossible to recognize whether the stop, cutting off perhaps 90 per cent. of the light, was in place or not as far as the light-ring was concerned. If, however, the stop was moved towards one side of the lens, as its approach to that side became very close, the bright ring seen around the black disk began to grow less bright on the corresponding side until there was a well-pronounced "rift." It is clear from the experiment that if the brightness of any portion of the edge of the artificial sun could be greatly increased there would have appeared the complement of this rift, namely, a "streamer."

This experiment, which is easily tried and highly interesting, is by no means conclusive, though very suggestive. The conditions, with the dimensions readily attainable to practice, much more nearly meet those of FRESNEL'S case than those of a total eclipse. Still, it must be regarded as a valuable guide in speculating on the nature of the corona. The first evident objection to applying the principle to the explanation of the corona is that it would seem to imply a rapid change in the extent of the corona during the eclipse, which according to it ought first to show much greater brightness and extent on the eastern side, then, near third contact, on the western side. There seems to be no ocular evidence of such change and but little photographic evidence. But there are considerations which greatly lessen the force of this objection. First, the change can only be rapid during a very brief interval after second contact and before third contact, so that it might readily escape observers whose attention is not specially directed to it; while, on the other hand, the camera cannot give evidence of rapid changes since, in the case of the outer corona, the exposure cannot be very short. Secondly, there is another reason why such changes should not be very great, namely, the rapid diminution in brightness of the sun's disk in approaching the limb. From this it follows that at second or third contact the sun could be replaced, as far as the phenomenon in question is concerned, by a uniformly bright disk of somewhat smaller dimensions, so that the ratio of the angular distances of the limbs, east and west, will not be indefinitely great or small.

Thus it seemed to me not an improbable explanation of the corona to attribute it to diffraction, though the reasoning upon which my conclusion was based was hardly of sufficiently definite character to justify its publication. When the expedition to observe the eclipse of last May was proposed, I thought, though there was no expectation in my mind of being one of the observers, that the theory might be rendered sufficiently probable to recommend a crucial test of its validity, if such could be devised. It was not difficult to find such a decisive test. According to the theory the corona should be particularly rich in *edge* light of the sun, that is, in chromosphere light. Since this is not subject to such a variation as light from the photosphere near the limb, the conclusion as to rapid change in the distribution of such light during the first and last seconds of totality is an essential part of the theory. On the other hand, if the bright lines of the coronal spectrum indicate an atmosphere about the sun, there can be no change in it due to the motion of the moon. This defines a pronounced and recognizable difference between the phenomena as demanded by the two theories. How this difference was made observable and the results of observation are given in the first part of this report.

It only remains to apply the theory to the explanation of the known characteristics of the corona to find how far it escapes the defects of the old one and what it leaves unexplained.

From it follows that the light of the corona consists in part of ordinary sunlight, a strong admixture of chromosphere light, together with such light as is reflected or radiated by particles of solid or liquid matter which are carried above the photosphere by convection currents or by the greater atmospheric disturbances which give rise to the prominences. As the strongest lines in the ordinary solar spectrum correspond roughly with the brightest lines of the chromosphere, in the composite spectrum of a corona thus formed the principle Fraunhofer lines must be wanting and even some of them reversed. The reversal, however, cannot depend in any way upon the vapor densities of the gases characterized by the lines, but almost exclusively on the brightness of that particular constituent of the chromospheric light. Thus the calcium lines H and K may be much more prominent than the hydrogen lines, as is probably the case. Again, the fact that the 1474 K line is recognized so much higher in the corona than the hydrogen lines leads to no such contradiction as to the relative densities of the corresponding vapors as we have seen to be the case in the ordinary theory, since it only implies that the material indicated by 1474 K shines with a greater brightness. Whether this implied intensity of the green line in the ordinary spectrum of the chromosphere is in accord with observations or not I think it impossible to assert. Certainly, in view of the facts that it is only found in the closest proximity to the photosphere and that it lies near the most brilliant portion of the spectrum where diffused light would do most to blot it out, we must consider its visibility under any circumstances as a proof of extraordinary brightness.

The diffraction theory also demands that the relative proportion of chromospheric light should diminish in leaving the sun, hence the spectrum of the outer corona should more closely resemble that of ordinary feeble daylight. STONE's observations of 1874 seem to afford strong evidence that this is the case, for he detected Fraunhofer lines at a distance from the sun though they were absent at the base of the corona.

Any variations in the intensity of the light near the limb of the sun must produce corresponding variations in the brightness of neighboring portions of the corona; a brighter area would give rise to a streamer, and an area of deficient light to a rift. We know from photographs of the solar surface that there are such variations of enormous magnitude, especially in those latitudes where sun spots are frequent. It is just at those regions that the rifts and streamers are most abundant and well marked. It is evident from the nature of the argument that a diffraction corona would appear as though arranged with reference to a disk, not a globe; thus the feature so puzzling in the generally accepted theory is a necessary consequence of the views here urged.

I have attempted to show in a paper on the physical constitution of the sun * that the photosphere is the locus of precipitation of some substance, very likely carbon, of very high vaporizing point; above this everything precipitated is, according to KIRCHOFF'S principle, relatively dark. It will probably be regarded as proved there, that the substance producing the general absorption at the sun's limb is either liquid or solid matter in a state of fine subdivision. Granting this, it follows that a particle immediately above the photosphere and within an ascending current, that is, over a granule, will be illuminated chiefly from below. Moreover, in accordance with the argument developed in the paper cited and which is too long to insert here, the illumination would be by light in which the Fraunhofer lines are necessarily very faint. Now, if the supposed particle is small enough, it will diffuse light which would be perfectly polarized in a direction at right angles to the direction of illumination, and the plane of polarization would be that of reflection. Perhaps the nearest possible experimental approach to the condition of an ascending column of gas in the sun which the theory cited supposes, is the flame of a lamp when smoking. Such flames I have investigated, and find that the upper portion emits light very strongly polarized in the direction anticipated. If, then, the constitution of the photosphere is as assumed, it follows that just above it is a region where light is scattered tangentially to the sun with strong radial polarization. According to the diffraction theory the corona from such a sun must be strongly polarized at its base, where this light is relatively strong, and continuously decrease outwards; a conclusion exactly contrary to the dicta of the old theory and in perfect accordance with observation.

Thus, without contradicting any principle of physics, the diffraction theory accounts for all the observed features of the corona with a single exception, namely, its more minute structure. Neither hypothesis succeeds here, at least if we accept all the curved forms indicated in the engraved interpretation of the photographs. I will only add in this connection that every irregularity in the limb of the moon must cause an irregularity in the light of a diffraction corona, which, not improbably, may be of a wisp-like form; but at present both theory and experience fail to give precise indications.

Since the telegram announcing the results of the Eclipse Expedition was published I have seen some statements that the visibility of the corona before second and after third contacts, and the detection of the outline of Venus before it had entered on the sun or after it had passed off, were definite proofs of the existence of an objective corona. I need hardly say that, in the case of the moon, the fundamental principles of the theory offered demands such a phenomenon. From the visibility of Venus near the sun we can derive a very strong argument against the existence of an objective corona, for, since the corona is strongest near the sun, that side of Venus nearest the sun ought to be the most readily perceived. Instead of this being true, that side has never been observed, though the more distant limb has frequently been seen.†

Yours, very respectfully,

CHARLES S. HASTINGS.

* Proc. Amer. Acad. Sci., Amer. Jour. Sci., Vol. , p. .

† The optical principles involved in this phenomenon have been discussed in the Sidereal Messenger by the writer.

(c.) *REPORT OF MR. C. H. ROCKWELL.*

Prof. E. S. HOLDEN:

DEAR SIR: At the time of the eclipse of May 6, 1883, I had a spectroscope with a grating of 14,400 lines to the inch attached to a telescope of 4 inches aperture, using a spectrum of the first order.

The grating was so adjusted that the region from a little below E to F was in the field. The slit was narrow, and was not changed; it was set tangential to the limb of the moon.

I did not notice any flash or other phenomena at the time totality commenced.

Owing, perhaps, to a passing cloud, I did not see the line K 1474 for the first minute and a half; it then came somewhat suddenly very distinctly into view, and I was able to follow it 4′ or 5′ to the west of the disk of the moon. I repeated this observation a second time with the same result.

I saw also two green lines, probably magnesium, each of them brighter and broader than 1474, but much shorter. I saw these two lines each time when I followed 1474 into the corona, but failed to see them when I turned the spectroscope to the north and south sides of the moon. Neither did I see 1474 save on the western side, as already mentioned.

As compared with the eclipse of July, 1878, observed at Central City, Colorado, I should say the darkness was less intense on this occasion.

It is proper to add, however, that in 1878 I had been reading a chronometer with the aid of a lantern before looking at the corona, while on this occasion I had not used any artificial light for any purpose.

Very respectfully,

CHARLES H. ROCKWELL.

CAROLINE ISLAND, *7th May*, 1883.

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(d.) *REPORT OF MR. ERASMUS D. PRESTON.*

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HONOLULU, *June* 1, 1883.

Prof. E. S. HOLDEN,

*Chief United States Eclipse Expedition:*

DEAR SIR: I have the honor to submit you a report of my observations in connection with the Total Solar Eclipse of May 6, 1883. In obedience to instructions from Prof. J. E. HILGARD, Superintendent of the U. S. Coast and Geodetic Survey, I left Washington February 28, and reported to you in New York the following day.

During the voyage out some preliminary computations were made. An extended list of stars was selected, suitable for time observations either at Flint or Caroline Island, their factors computed and checked,* and pairs of stars were chosen for observations for latitude by the method of equal zenith distances.

The instruments furnished by the Coast and Geodetic Survey are as follows:

INSTRUMENTS.

TRANSIT.

U. S. C. S. Transit No. 2, made by TROUGHTON & SIMMS, of London, to which a delicate level was attached before leaving Washington, for the determination of latitude. The aperture of the telescope is $2\frac{3}{4}$ inches with a focal length of 46 inches, and a diagonal eye-piece was used giving a magnifying power of 110. The field of view was 12 minutes of arc, one division of striding level =

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* The factors A, B, and C for a small list of time stars were computed at Madison by Mr. PENNOCK, one of my pupils, and handed to Mr. PRESTON for his use.—E. S. H.

0″.83—one division of latitude level = 1″.75. Correction for pivot inequality, inappreciable. A glass diaphragm was used, having ruled upon it 13 lines. The equatorial intervals of the three tallies, determined on the island from the transits of ten stars of varying declination, are as follows:

*Equatorial Intervals, Clamp West.*

| | s. |
|---|---|
| B—1 | − 14.50. |
| 2 | − 12.07. |
| 3 | − 9.66. |
| C—1 | − 4.82. |
| 2 | − 2.43. |
| 3 | − .01. |
| 4 | + 2.41. |
| 5 | + 4.82. |
| D—1 | + 9.67. |
| 2 | + 12.06. |
| 3 | + 14.49. |

CHRONOGRAPH.

Chronograph No. 8, made by FAUTH & Co., of Washington, was used in all time and pendulum observations, and also in recording the observations of contacts during the eclipse. Two cells of the ordinary crow-foot gravity battery were in the circuit, which included two observing keys, a sounder, Sidereal chronometer (break-circuit), NEGUS No. 1589 with condenser and the chronograph.

CHRONOMETERS.

The two chronometers employed were NEGUS 1589 and HUTTON, 202 both Sidereal, and both supplied with a break-circuit attachment. The former breaks every second, omitting the 60th—the latter breaks every even second and also the 59th.

PENDULUM.

The pendulum swung was the Yard Reversible, PEIRCE No. 3, made at the Coast and Geodetic Survey Office in 1880. It is symmetrical in form with reference to the center of figure, and the ratio of the distance of the center of mass from the point of support for heavy end up and heavy end down is as one to three. It is made of brass with knife edges of steel, and was swung on steel plane.

A small reading telescope for observing the amplitude of oscillation of the pendulum.

A mercurial barometer, No. 1936, made by GREEN, of New York, and aneroid, by CASELLA, of London. Four thermometers, by BAUDIN, of Paris.

OBSERVATIONS FOR TIME AND LATITUDE.

The pier was finished Sunday afternoon, the 22d of April, but owing to cloudy weather no observations could be made until the evening of the 24th. From that date stars were obtained every evening about 7 o'clock until May 8, inclusive, with the exception of May 3, when wet weather again made it impossible to observe. Good sets were also obtained at about 4 o'clock on the mornings of April 26, 28, 29, 30, May 1, 2, 7 and 8, these morning observations being made in connection with the gravity experiments.

The method of equal zenith distances was employed for latitude, and this work was carried on at the same time as the pendulum work, thus filling up the time between the evening and morning time-observations. Latitude was thus observed on six nights, but, owing to difficulty with the micrometer thread, two of these nights were not satisfactory, and observations on one or two of the others were much interrupted by clouds. It was found that on account of the nature of the climate several spider threads, although tight when put in, became quite slack soon afterwards. The atmosphere was very moist at night, and during the day the heat was excessive in the transit tent. After trying with unsatisfactory results several spider threads brought along with us, and two parallel fine copper wires, which were unsatisfactory for other reasons, it was thought that perhaps a spider thread found on the island would be less affected by climatic influences than those previously tried. Accordingly one was found and put in. It was rather coarse, very strong, and capable of being stretched tightly, and this one lasted during all the remaining observations. M. PALISA, of the European Expedition, gave up his diaphragm of spider lines and substituted a glass one in its place.

The resulting value of the latitude deduced from four nights observations and 16 pairs is 10° 00′ 1″.6. This value may be changed slightly by the final reduction of all the pairs with somewhat improved star places. The following is a specimen of the reduction of 1 pair observed on four nights:

*United States Coast Survey. Latitude Computation.*

[Latitude station: Caroline Island. Instrument: Transit telescope No. 2, with latitude level.]

| Date. | Star. No. | Star. N. S. | Micrometer. Reading. | Micrometer. Diff. Z. D. | Level. N. | Level. S. | Level. Diff. N—S. | Declination. | Sum and half sum. | Corrections. Microm. | Corrections. Level. | Corrections. Refr. | Latitude. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | T. D. | T. D. | | | | ° ′ ″ | ° ′ ″ | ′ ″ | ″ | ″ | ° ′ ″ |
| April 29* . . | 269 | N | 30 39.5 | | 13.0 | 12.0 | | +14 18 6.90 | −19 46 35.25 | | | | |
| | 277 | S | 11 79.0 | 18 60.5 | 10.5 | 7.0 | +1.5 | −34 4 42.15 | −9 53 17.62 | −6 44.08 | +1.96 | −0.13 | −9 59 59.87 |
| May 4† . . . . . . . . | | N | 33 84.0 | | 7.0 | 10.0 | | 7.70 | 34.88 | | | | |
| | | S | 15 34.5 | 18 49.5 | 10.0 | 6.0 | +1.0 | 42.58 | 17.44 | −6 41.71 | +0.44 | −0.13 | 58.84 |
| May 7† . . . . . . . . | | N | 31 35.5 | | 7.8 | 11.0 | | 8.30 | 34.49 | | | | |
| | | S | 12 91.0 | 18 44.5 | 10.0 | 9.0 | −2.2 | 42.79 | 17.25 | −6 40.62 | −0.96 | −0.13 | 58.96 |
| May 8† . . . . . . . . | | N | 32 75.0 | | 14.5 | 3.1 | | 8.51 | 34.35 | | | | |
| | | S | 14 11.0 | 18 64.0 | 5.0 | 11.2 | +5.2 | 42.86 | 17.17 | −6 44.86 | +2.27 | −0.13 | 59.89 |
| Mean . . . . . . | | | | | | | | | | | | | −9 59 59.39 |

* E. D. P., observer. † S. J. B., observer.

| | Declination. |
|---|---|
| | ″ |
| One revolution of micrometer . . . . . . . . . . | =43.44 |
| One revolution of latitude level . . . . . . . . . . | = 1.75 |

| Pair. | Catalogue. | Latitude. $\varphi$ | $\Delta$ | $\Delta^2$ | No. of observations. | Weight. W. | W. $\varphi$ | W. $\Delta^2$ |
|---|---|---|---|---|---|---|---|---|
| | | ° ′ ″ | ″ | ″ | | | ″ | ″ |
| 386– 189 | H | −10 00 1.60 | 1.02 | 1.04 | 2 | .76 | 1.22 | .79 |
| 241– 244 | H | 1.01 | .43 | .18 | 4 | 1.18 | 1.19 | .21 |
| 731– 741 | L | 1.16 | .58 | .34 | 1 | .45 | .52 | .15 |
| 269– 277 | H | 59.39 | 1.19 | 1.42 | 4 | 1.18 | − .72 | 1.68 |
| 716– 730 | L | 1.25 | .67 | .45 | 2 | .76 | .95 | .34 |
| 919– 932 | L | 0.80 | .22 | .05 | 5 | 1.33 | 1.06 | .07 |
| 287– 292 | H | 0.21 | .37 | .14 | 3 | 1.00 | .21 | .14 |
| 6581– 6593 | S | 0.72 | .14 | .02 | 2 | .76 | .55 | .02 |
| 1112– 1121 | S | 1.88 | 1.30 | 1.69 | 2 | .76 | 1.43 | 1.28 |
| 10584–10609 | S | 0.55 | .03 | .00 | 3 | 1.00 | .55 | .00 |
| 1232–10740 | S | 0.96 | .38 | .14 | 3 | 1.00 | .96 | .14 |
| 8860– 861 | S | 0.80 | .22 | .05 | 3 | 1.00 | .80 | .05 |
| δ Virg.– 7173 | S | 58.70 | 1.88 | 3.53 | 1 | .45 | − .58 | 1.59 |
| 10934–11002 | S | 59.50 | 1.08 | 1.17 | 2 | .76 | − .38 | .89 |
| 1232–10765 | S | 0.20 | .38 | .14 | 3 | 1.00 | .20 | .14 |
| Mean . . | . . . . . . | 10 00 00.58 | Sums. . . . . . . . . . . . . | | | . . . .13.39 | 7.96 | 7.49 |

The unusual thickness of the spider thread is the cause of the large probable error of observation. The latitude is deduced from forty measures on 15 pairs. The tables show the reduction of one pair observed on several nights, and the general summary of all the results. The last table gives the result for the individual pairs, the number of observations on a pair, and the weight assigned to each result.

The probable error of observation ($e$) deduced by comparing each individual result with the mean result for the pair is $\pm$ 0″.69.

Probable error of resulting latitude from any one pair depending on the probable error of observation and the probable error of the mean of two declinations is $e = \pm$ 0″.58.

$$\text{Weight of result by a pair} = \frac{n}{ne^2_\delta + e^2} = \frac{n}{\cdot 10\, n + \cdot 48}$$

where $n$ is the number of observations and $e^2$ the prob. error of the mean of two declinations.

$$\text{Value of latitude from all the pairs} = \varphi_0 = \frac{\Sigma\, w\, \varphi}{\Sigma\, w} = 10^\circ\ 00'\ 00''.59.$$

$$\text{Probable error of latitude from all the pairs} = \sqrt{\frac{\cdot 455\ \Sigma\, w \smile \varphi^2}{(p-1)\ \Sigma\, w}} = 0''.13$$

where $p$ is the number of pairs and $w$ = weight.

The latitude of station is then

$$-10^\circ\ 00'\ 00''.59 \pm 00''.13$$

DETERMINATION OF TIME.

Whenever it was possible to adhere to it the following plan was followed: The inclination of the telescope axis was determined, then a low north star, a low south star, and several stars within 15° of the zenith were observed, after which the inclination was again determined. The telescope was then reversed and the same programme repeated. Circumstances, however, did not always admit of this scheme being literally carried out. The inclination was always taken at least every fifteen minutes, and stars low enough for azimuth were observed, except in one position on one night, when it was not possible. The preliminary reduction of the transits was made on the island by Mr. W. UPTON, of the Signal Service, and the final reduction by me in part at sea during the voyage from Caroline Island to Honolulu and in part at the latter place.

In the final reduction the method of least squares was applied. Each star gave a conditional equation of the form

$$S\,T + a\,A = \alpha - T - \triangle\,T$$

after having corrected the observed transit for rate of chronometer, inclination of axis, and collimation and observation. Each conditional equation is multiplied by the square root of the weight of the observation depending on the star's declination, and the number of threads observed, and then the normal equations are formed in the usual way. The reduction for May 7 is given in full.

## DETERMINATION OF TIME.

[Caroline Island, South Pacific Ocean, May 7, 1883. Epoch, $9^h\ 30^m$. Daily rate, $+3^s.5$. Collimation, $-0^s.1$. Clamp west.]

| Star. | C. | Transit. | Corrections. Rate. | Level. | Coll. | Ab. | F. | $a$ | $a-t$. |
|---|---|---|---|---|---|---|---|---|---|
| | | *h. m. s.* | *s.* | *s.* | *s.* | *s.* | *s.* | *h. m. s.* | *s.* |
| κ Caneri | W | 9 0 52.18 | —.07 | .00 | —.10 | —.02 | 51.99 | 9 1 26.22 | +34.23 |
| δ Hydræ | W | 7 44.11 | —.06 | .00 | —.10 | —.02 | 43.93 | 8 18.26 | +34.33 |
| β Argus | W | 11 20.84 | —.05 | .00 | —.28 | —.06 | 20.45 | 11 56.00 | +35.55 |
| α Hydræ | W | 21 17.70 | —.02 | .00 | —.10 | —.02 | 17.56 | 21 51.99 | +34.43 |
| 10 Leonis | E | 26 30.89 | .01 | —.10 | +.12 | —.03 | 30.87 | 27 5.05 | +34.18 |
| υ Urs. Maj | E | 42 7.60 | +.03 | —.05 | +.20 | —.04 | 7.74 | 42 41.72 | +33.98 |
| 6 Sextantis | E | 44 47.79 | +.04 | .08 | +.10 | —.02 | 47.83 | 45 22.16 | +34.33 |
| π Leonis | E | 53 29.39 | +.06 | —.03 | +.10 | —.02 | 29.50 | 54 3.71 | +34.21 |
| λ Hydræ | E | 10 4 20.50 | +.09 | —.03 | +.10 | —.02 | 20.64 | 4 55.04 | +34.40 |

[May 7, 1883. Clamp west. $\Delta T = 34^s.40$.]

| Star. | $\tau$ | $d$ | A | $p$ | $p$A | $p$A² | $p\delta$ | $p$A$\delta$ | $a$A | ΔT | Δ | $p$Δ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | *s.* | *s.* | | |
| κ Caneri | +34.23 | — .17 | — .36 | 1.00 | — .36 | .13 | —.17 | +.06 | — .17 | +34.40 | +.02 | +.02 |
| δ Hydræ | +34.33 | — .07 | — .22 | 1.00 | — .22 | .04 | —.07 | +.01 | .10 | .43 | —.01 | —.01 |
| β Argus | +35.55 | +1.15 | +2.42 | 0.31 | + .75 | 1.81 | +.36 | +.86 | +1.14 | .41 | +.01 | .00 |
| α Hydræ | +34.43 | + .03 | — .03 | 1.00 | — .03 | .00 | +.03 | —.00 | + .01 | .42 | .00 | .00 |
| | | | | 3.31 | + .14 | 1.98 | +.15 | +.93 | | | | +.01 |

*Normal equations:*

$3.31\ \delta T + .14a = +0^s.15;\ +.14\ \delta T + 1.98a = +0^s.93.$ Hence $a = +0^s.47;\ \delta T = +0^s.02;\ \Delta T = +34^s.42.$

[May 7, 1883. Clamp east.]

| Star. | $\tau$ | $d$ | A | $p$ | $p$A | $p$A² | $p\delta$ | $p$A$\delta$ | $a$A | ΔT | Δ | $p$Δ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *s.* | | | | | | | | | *s.* | | |
| 10 Leonis | +34.18 | — .22 | — .91 | .85 | — .77 | .70 | — .19 | +.17 | — .18 | +33.36 | —.01 | —.01 |
| υ Urs. Maj | +33.98 | — .42 | —1.85 | .52 | — .96 | 1.78 | —.22 | +.40 | — .37 | .35 | .00 | .00 |
| 6 Sextantis | +34.33 | — .07 | — .11 | 1.00 | — .11 | .01 | —.07 | +.01 | — .02 | .35 | .00 | .00 |
| π Leonis | +34.21 | — .19 | — .32 | 1.00 | — .32 | .10 | —.19 | +.06 | — .06 | .27 | +.08 | +.08 |
| λ Hydræ | +34.40 | .00 | + .03 | 1.00 | + .03 | .00 | .00 | .00 | + .01 | .39 | —.04 | —.04 |
| | | | | 4.37 | —2.13 | 2.59 | —.67 | +.64 | | | | +.03 |

*Normal equations:*

$4.37\ \delta T - 2.13a = -0^s.67;\ -2.13\delta T + 2.59a = +0^s.64.$ Hence $a = +0^s.20;\ \delta T = -0^s.05;\ \Delta T = 34^s.35.$

At epoch $9^h\ 30^m$ chronometer correction $= +34^s.38$.

The following table exhibits the residuals of each star for the several nights:

TABLE OF STAR RESIDUALS.

| Star. | α | δ | ζ | April. 24 | 25 | 27 | 28 | 29 | 30 | May. 1 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | h. m. | | ′ | | | | | | | | | | | | |
| α Argus | 6 21 | −52 38 | 42 38 | +.01 | | | | | | | | | | | |
| α Canis Maj | 40 | −16 34 | 6 34 | .06 | | | | | | | | | | | |
| ε Canis Maj | 51 | −28 49 | 18 49 | +.07 | | | | | | | | | | | |
| δ Canis Maj | 7 4 | −26 13 | −16 13 | −.02 | | | | | | | | | | | |
| α Canis Min | 33 | + 5 31 | +15 31 | .00 | | | | | | | | | | | |
| β Gemini | 38 | +28 18 | +38 18 | +.02 | | | | | | | | | | | |
| β Cancri | 8 10 | + 9 32 | +19 32 | | −.04 | | | | | | | | | | |
| 31 Lyncis | 15 | +43 34 | +53 34 | | +.02 | | | | | | | | | | |
| Br. 1197 | 20 | − 3 32 | + 6 28 | | | | | | .01 | | | | | | |
| δ Hydræ | 32 | | | | | | | | +.03 | | | | | | |
| α Mali | 39 | | | | | | | | .00 | | | | | | |
| ε Hydræ | 39 | + 6 51 | +16 51 | | | | | | | | | −.01 | | | |
| ξ Hydræ | 49 | + 6 23 | +16 23 | | +.01 | | | | | −.01 | .04 | −.05 | | | |
| ι Urs. Maj | 51 | +48 30 | +58 30 | | | | | | −.01 | +.01 | | | | | |
| α Cancri | 52 | +12 18 | +22 18 | | +.11 | | | | | | | −.03 | | | |
| 4 Urs. Maj | 56 | +47 37 | +57 37 | | −.02 | | | −.02 | | | | | | | |
| κ Cancri | 9 1 | +11 8 | +21 8 | | −.02 | | | −.15 | −.03 | +.01 | .00 | | | +.02 | |
| ζ Hydræ | 8 | + 2 18 | +12 18 | | | | | +.02 | +.05 | −.03 | +.01 | +.06 | .00 | −.01 | |
| β Argus | 12 | | | | | | | | | −.02 | +0.1 | +.06 | +.09 | .00 | |
| 40 Lyncis | 14 | | | | | | | +.09 | | | | | | | |
| α Hydræ | 22 | − 8 9 | + 1 51 | | −.07 | | | +.08 | −.03 | +.01 | −.06 | | −.02 | .00 | |
| 10 Leonis | 27 | +36 55 | +46 55 | | | | | | | −.09 | −.14 | | | −.01 | |
| ο Leonis | 34 | +10 25 | + 2 25 | | | | | | | | | | +.04 | | |
| ε Leonis | 39 | +24 19 | +34 19 | | | | | | | | | | | | |
| υ Urs. Maj | 43 | +59 35 | +69 35 | | | | | | | | | | | .00 | |
| 6 Sext | 45 | − 3 42 | + 6 18 | | | | | .00 | | +.06 | −.06 | +.05 | | .00 | |
| π Leonis | 54 | + 8 36 | +18 36 | | | +.04 | | +.02 | | .00 | +.02 | +.05 | −.11 | +.08 | −.06 |
| α Leonis | 10 2 | +12 32 | +22 32 | | | | | | | | | | | | −.04 |
| λ Hydræ | 5 | −11 47 | − 1 47 | | | −.03 | | | | | | −.01 | −.03 | −.04 | −.01 |
| λ Urs. Maj | 10 | +43 30 | +53 30 | | | | | | | | | | | | +.02 |
| μ Urs. Maj | 15 | +42 5 | +52 5 | | | −.01 | | −.01 | | | +.09 | −.13 | −.04 | | |
| μ Hydræ | 20 | −16 15 | − 6 15 | | | | | | | | | +.04 | | | |
| α Ant'li | 22 | −30 29 | −20 29 | | | −.03 | | | | | | | | | |
| ρ Leonis | 26 | + 9 54 | +19 54 | | | | | | | | | | −.02 | | |
| 33 Sext | 35 | − 1 8 | + 8 51 | | | | | | | | | | | | +.10 |
| τ Hydræ | 43 | | | | | −.08 | | | | | | | | | +.07 |
| d Leonis | 55 | + 4 15 | +14 15 | | | +.05 | | | | | | | | | |
| α Urs. Maj | 57 | +62 23 | +72 23 | | | | −.05 | | | | | | −.03 | | −.03 |
| χ Leonis | 59 | + 7 58 | +17 58 | | | | | | | | | | +.12 | | +.09 |
| β Crater | 11 6 | −22 12 | −12 12 | | | +.07 | −.05 | | | | | | .00 | | −.12 |
| δ Leonis | 8 | +21 10 | +31 10 | | | | +.16 | | | | | | | | |
| σ Leonis | 15 | + 6 40 | +16 40 | | | | −.08 | | | | | | | | |
| τ Leonis | 22 | + 3 30 | +13 30 | | | | +.09 | | | | | | | | |
| ξ Hydræ | 27 | −31 13 | −21 13 | | | | −.17 | | | | | | | | |
| ι Leonis | 31 | − 0 11 | − 9 49 | | | | +.10 | | | | | | | | |
| χ Urs. Maj | 40 | +48 25 | +58 25 | | | | −.06 | | | | | | | | |
| β Virgin | 45 | + 2 25 | +12 25 | | | | +.07 | | | | | | | | |

The corrections to Negus 1589, from the beginning to the end of the star observations were as follows:

| Date. | Epoch. | Correction to 1589. | Corrections for uniform rate from beginning to end. | Diff. |
|---|---|---|---|---|
| | *h. m.* | *s.* | *s.* | *s.* |
| April 24 | 7 00 | −11.95 | −11.95 | .00 |
| 25 | 8 45 | − 8.02 | − 8.16 | + .14 |
| 27 | 10 29 | − 0.31 | − 0.85 | + .54 |
| 28 | 11 21 | 3.35 | + 2.80 | + .55 |
| 29 | 9 36 | + 6.68 | + 6.07 | + .61 |
| 30 | 8 50 | + 10.48 | + 9.49 | + .99 |
| May 1 | 9 22 | +14.15 | +13.09 | +1.06 |
| 4 | 9 31 | +23.97 | +23.70 | + .27 |
| 5 | 9 29 | +27.25 | +27.22 | + .03 |
| 6 | 10 6 | +30.83 | +30.84 | − .01 |
| 7 | 9 30 | +34.38 | +34.28 | + .10 |
| 8 | 10 29 | +37.95 | +37.95 | .00 |

OBSERVATIONS OF THE CONTACTS.

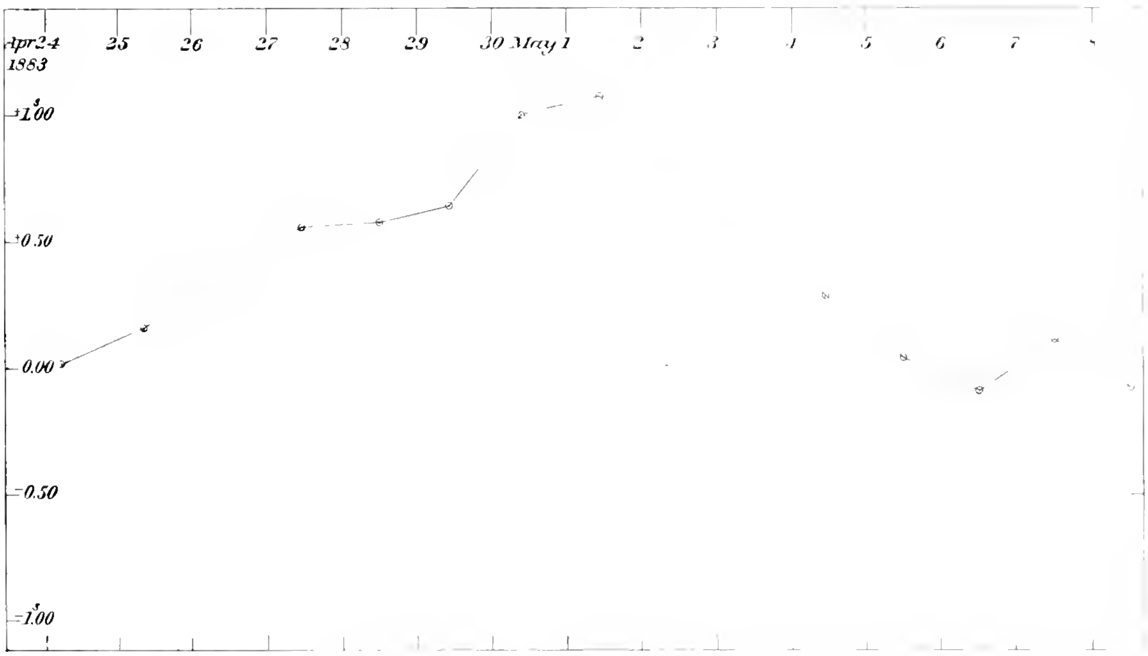
In observing the four contacts of the solar eclipse a small telescope of 3½ inches aperture was used. A magnifying power of about 100 was used. I took my place at the telescope three minutes before the computed time of first contact, directed it towards the sun, and verified the adjustments which had been made some time previously. The definition was found to be perfect, the atmosphere was clear, for we had had a heavy rain shower 40 minutes before, and the image of the sun steady. The sun was placed near the center of the field, and then a rest of one minute was taken before beginning to look. The point of the sun's limb at which the moon was to appear was watched eagerly, as was also an arc of probably 10° on either side. When the computed time was up and no moon was seen, I still glanced at the predicted point once every second, but widened the arc so that any indentation in the sun's limb would be detected within an arc of 20° on either side. Fifteen seconds after the computed time I thought I noticed a change in the appearance of the sun's limb, and one and a half seconds later, noted by a sounder at my side, I became convinced that I was looking at the moon's advancing limb and instantly made a signal, which was registered on the chronograph chronometer NEGUS 1589, at $1^h\ 0^m\ 33.3^s$. This made the time of first contact at $1^h\ 00^m\ 31.8^s$. NEGUS 1589 was keeping very nearly local sidereal time. No roughness was noticed on the moon's limb either at first contact or soon thereafter, and no intimation of her presence was had before she impinged upon the sun's limb. At $2^h\ 8^m$ we noticed the first appearance of decided gloom. In the east the horizon appeared as it does late at sunset, with a yellowish tinge, which deepened and became darker until totality set in. Mr. W. B. FLETCHER was calling aloud the minutes of time to elapse before the computed time of second contact, and when he called "Two" I again took my place at the telescope. The visible portion of the sun was now reduced to a very thin crescent, and at $2^h\ 28^m\ 18^s$ BAILY'S beads first appeared. At this moment they were seen only at the southern point of the crescent. It was not until $2^h\ 28^m\ 52^s$ or 6½ seconds before second contact that they were seen in profusion. Second contact was noted at $2^h\ 28^m\ 58.5^s$.

During the 300 seconds immediately following second contact I was engaged in polariscopic observations. At the end of this time I returned to the telescope. At $2^h\ 34^m\ 11.9^s$, the red chromosphere was quite apparent on the west of the moon. This was noted on the chronograph by a peculiar signal, to avoid mistaking it for the third contact signal. The color of the chromosphere grew more and more intense as the time elapsed until at $2^h\ 34^m\ 24.0^s$ the first ray of true sunlight appeared, which was as unmistakable in its character as the flash of a spark of electricity. Coming after the darkness of a long totality it reminded one strongly of the outburst of an electric

Fig. 21.

CAROLINE ISLAND, SOUTH PACIFIC OCEAN.

[Corrections to Negus 158, after applying uniform rate.]



light, and made an impression not only very positive in its character at the time, but one not soon forgotten. During totality it was necessary to have a lantern to read a silvered circle. The same circle was read in Colorado in 1878 by Dr. HASTINGS without any artificial illumination.

The time of fourth contact was noted on the chronograph at $4^h\ 8^m\ 5.8^s$, and was independently noted by Mr. C. H. ROCKWELL by eye and ear method at $8^m\ 6.0^s$ by same chronometer.

The corrections to Negus 1589 on May 6 were as follows:

| Mean time. | Sidereal time. | | Correction to 1589. |
|---|---|---|---|
| | *h.* | *m.* | *s.* |
| 10 a. m | 0 | 57 | +29.63 |
| 11 a. m | 1 | 57 | 29.79 |
| 12 m | 2 | 58 | 29.95 |
| 1 p. m | 3 | 58 | 30.11 |
| 2 p. m | 4 | 58 | 30.26 |

The true local sidereal and mean times of contacts, adopting $4^h\ 52^m\ 48^s$ as the longitude of Caroline Island, were then as follows:

| | Sidereal time. | | | Mean time. | | |
|---|---|---|---|---|---|---|
| | *h.* | *m.* | *s.* | *h.* | *m.* | *s.* |
| 1st contact | 1 | 1 | 1.4 | 10 | 3 | 41.6 a. m. |
| 2d contact | 2 | 29 | 28.4 | 11 | 31 | 54.1 a. m. |
| 3d contact | 2 | 34 | 53.9 | 11 | 37 | 18.7 a. m. |
| 4th contact | 4 | 8 | 35.9 | 1 | 10 | 45.4 p. m. |
| Duration of totality | | 5 | 25.5 | | 5 | 24.6 |

The experiments to determine the force of gravity at Caroline Island were made from 7 p. m. to 5 a. m., the pendulum being swung four nights with heavy end down, and two nights with heavy end up; 100 transits of the pendulum-point across the vertical wire of the telescope were noted at the beginning and end of each swing by breaking the electric current and thus registering the transit on the chronograph. "Donkey" transits were also taken during the swing to avoid mistaking the whole number of oscillations. The amplitudes of oscillation of the pendulum before and after each set of regular transits, and frequently during the swing, was noted. The barometer was read several times during the night and the temperature was noted, by means of three thermometers, continually. The range of temperature. however, was not great. My colleague in the work has been Ensign S. J. BROWN, U. S. Navy. He took part in all observations except those for time. It was thought best to have one person continue these during our whole stay on the island in order that they might not be influenced by a change of personal equation.

I am, most respectfully, your obedient servant,

ERASMUS D. PRESTON,
*Aid U. S. C. & G. Survey.*

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*(c) REPORT OF MR. WINSLOW UPTON.*

U. S. S. HARTFORD, *May* 23, 1883.

Prof. E. S. HOLDEN:

DEAR SIR: I have the honor to submit herewith a report upon the observations made by me in connection with the recent solar eclipse. The work intrusted me was (1) determination of the longitude of the observing station* ; (2) observations with a prismatic spectroscope during the total phase ; (3) meteorological observations during the occupation of the station and especially at the time of the eclipse ;† (4) observations of the first and fourth contacts.

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## SPECTROSCOPIC OBSERVATIONS DURING THE ECLIPSE.

The plan of spectroscopic work designed by Dr. HASTINGS included observations with prismatic spectroscope, which were assigned to me. The instrument used was a telescope made by GRÜNOW, belonging to Mr. C. H. ROCKWELL. It has an aperture of 2¼ inches, a focal length of 30 inches, and was for these observations furnished with an eye-piece magnifying 29 diameters. Before the objective of this instrument was placed a prism of flint glass, having a refracting angle of 30°. The refracting edge of the prism was placed parallel to the polar axis of the telescope in order that the spectrum might extend in the field of view in the direction of the diurnal movement of the heavens. By this means a slight movement of the telescope upon the polar axis only was sufficient to keep the spectrum in the field during the total phase of the eclipse. The apparatus was mounted equatorially upon a simple tripod, and was adjusted with its polar axis approximately in the meridian and elevated to an angle of 10°. At the time of observation, the telescope pointed east of the sun.

With this instrument I was requested to make a special study of the coronal rings, to note what changes occurred during the progress of totality and to estimate the relative brightness and height of the several rings at mid-eclipse. In addition, it was designed to estimate the duration of the reversal of the Fraunhofer lines if this reversal was seen.

In order to form an estimate of the appearance of the spectrum in the instrument, I attached to it, the day preceding the eclipse, a slit and collimator and examined the spectrum thus formed. The field of view was sufficient to take in the portion of the spectrum included between B and F, and the principal lines between these limits were plainly seen.

During the partial phase preceding totality, the encroachment of the moon upon the spectrum enabled me to properly focus the instrument. The solar spectrum, while complete on its violet end, was cut off at the red end by the advancing moon. The obscuration affected the apparent lower portion of the red end, but not the whole of it, since the moon was moving from a point several degrees south of west, and the lunar cusp gave a narrow horizontal spectral line, which was capable of a sharp focus. Seventeen minutes before the total phase began, indications were noted of the formation of the Fraunhofer lines on the lower edge of the spectrum. Eight minutes before the total phase, the principal lines were sharply defined.

Five seconds after the beginning of totality four curved lines were seen, in the expected positions of the lines C, $D_3$, 1474, and F. A light cloud immediately afterward obscured the sun and obliterated the lines: on its passage and the return of the spectrum, a small line, of about one-third the height of the others, was seen between the third and fourth. One hundred seconds after the beginning of totality, the coronal rings supplanted the lines above described, in color red, yellowish green, and green, supposed to be C, $D_3$, and 1474. They overlapped each other, and the exact outlines of the overlapping portions could not be made out. At mid-eclipse a careful estimate of their width was made ; the first (at the red end) was of the same width as the second, but the third was over one-half this width. The estimates above given refer to the width on the eastern or western sides. The width could not be estimated on the upper and lower portions on

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* This is given in IV, §.

† This is given in IV, § 4.

account of the overlapping of the rings. The absolute width of any one of the rings was not estimated at the time, but it was recalled shortly after the eclipse that the width of the green ring was about equal to three quarters of the distance between E and F, as seen with the same prism and telescope.

At the expiration of two hundred seconds of totality, immediately after the above obseuration, it was noted that the red ring was decidedly the brightest, and it continued to increase in brightness relative to the others during the next sixty seconds. In this interval, also, three spots of light were seen, red, yellow, and green, due to solar prominences, and when two hundred and ninety seconds had passed, the four curved lines seen at the beginning of totality were again observed.

The phenomena attending the reversal of the lines were especially noted at the close of the totality, the reversal not being seen at the beginning of totality either on account of the removal of the dark shade at about that time or on account of clouds which may have then prevailed as they were seen a few seconds later. As the end of totality approached, a large number of narrow bright lines were seen and observed for several seconds before the corresponding dark lines appeared. The change was instantaneous, or nearly so, the bright lines having been seen for an interval estimated as five seconds, the wind preventing the chronometer beats from being actually counted.

During the second partial phase the dark lines were seen for twelve minutes after the end of totality.

In making the above observations I was assisted by Ship's Printer T. J. BROOKS, of the U. S. S. Hartford, who acted as recorder. I dictated to him occasional words at intervals during the totality and also the corresponding times as announced by Mr. FLETCHER. From these records, which were written out more fully during the second partial phase, the above report is derived.

### OBSERVATIONS OF THE FIRST AND FOURTH CONTACTS.

These were made with the $2\frac{1}{2}$ inch glass used in the spectroscope observations, but with a magnifying power of 63. The time was recorded by Mr. W. B. FLETCHER with chronometer Hutton 202. The following is the record:

FIRST CONTACT.

| *h.* | *m.* | *s.* | |
|---|---|---|---|
| — | — | 23. | Suspected: not verified. |
| — | — | 33.5. | Suspected: not verified. |
| — | — | 41.5. | Suspected: not verified. |
| 1 | 0 | 48.5. | Seen: not too late by more than $2^s$. |

The chronometer had a correction of $+9^s.3$ on local sidereal time. The above time reduces to $10^h\ 3^m\ 38^s.0$ local mean time.

FOURTH CONTACT.

| *h.* | *m.* | *s.* | |
|---|---|---|---|
| 4 | 8 | 9. | Still seen. |
| 4 | 8 | 14. | Still seen. |
| 4 | 8 | 16. | Sharp projection on the moon's disk goes off. |

The chronometer had a correction of $+9^s.5$ on local sidereal time. The above time reduces to $1^h\ 10^m\ 35^s.0$ local mean time.

It will be observed that this observation is about ten seconds earlier than those of the other observers of fourth contact. This discrepancy I can explain only on the supposition of an error of $10^s$ by the time-keeper. The observation was peculiarly good on account of the sharp projection noted on the moon's disk, and could scarcely have been in error $2^s$ as the definition was good.

On the other hand, the original pencil record of the time is plain, and there can be no doubt that the time was noted as given above.

I have the honor to be, very respectfully, yours,

WINSLOW UPTON.

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*REPORT OF ENSIGN S. J. BROWN, U. S. NAVY.*

U. S. S. HARTFORD, AT SEA,
(Long. 147° W., lat. 2° S.)

Prof. EDWARD S. HOLDEN:

SIR: Having been detailed by the Navy Department as a member of the U. S. Solar Eclipse Expedition, in accordance with the instructions contained in my orders, I conferred in regard to my duties with Prof. J. H. C. COFFIN, U. S. Navy, secretary of the committee of the National Academy of Sciences on the Solar Eclipse. I was given written instructions to the effect that the committee desired me, in all my scientific work, to place myself under your instruction and directions as chief and scientific head of the expedition.

In pursuance of those instructions I have the pleasure to submit to you the report of my work.

I left the Naval Observatory February 28, taking with me the following instruments: 4-inch comet-seeker, 42-inch focal length; 3½-inch equatorial, 42-inch focal length; sextant and artificial horizon; two chronometers.

By your direction I took charge of all the chronometers in the party, intending to use them in determining the chronometric longitude of the place selected for the observations. But after leaving Callao, Peru, on account of sickness and great prostration, I gave up the care of the chronometers to Mr. UPTON. Subsequently my duties connected with the gravity experiments and observations for latitude took up my time so completely that I could not resume charge of them.

With the comet-seeker I had planned to sweep during totality for intra-mercurial planets. To aid in this, I had constructed a chart, embracing stars of the 7.5 magnitude, and extending 32° in R. A., and 16° in declination in the neighborhood of the eclipsed sun. But after a full discussion with yourself and Dr. HASTINGS, as to the greater importance of certain spectroscopic observations which you wished to have made, I decided, in deference to your wishes, to use instead an integrating spectroscope devised by Dr. HASTINGS.

My work on the island comprised, (I), spectroscopic observations; (II), computation of time of contacts and observations of the first and fourth; (III), pendulum observations in conjunction with Mr. E. D. PRESTON, U. S. Coast and Geodetic Survey, including observations for latitude.

## I. SPECTROSCOPIC OBSERVATIONS.

In these observations I used an integrating spectroscope with an effective aperture of $\frac{15}{16}$ inch and a magnifying power of 9. During the passage from Callao to the Island, I used the spectroscope frequently to familiarize myself with relative positions of the Fraunhofer lines. After our arrival, the effectiveness of the instrument was much increased by placing a double concave lens between the slit and the objective of the collimator. The instrument was devised by Dr. C. S. HASTINGS, who was in charge of all spectroscopic work, and a full description of it will be found in his report. It was attached to the 3-inch equatorial,* which was pointed by Passed Assistant Surgeon W. S. DIXON, U. S. Navy, who used it at the same time on making sketches of the corona.

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* The instrument used by Mr. BROWN was strapped to the outside of the tube of Dr. DIXON's telescope, which was constantly pointed at the sun's center.—E. S. H.

The plan of observations laid out by Dr. HASTINGS was as follows:

(1.) To observe the reversal of the Fraunhofer lines and endeavor to estimate their duration

(2.) To note what lines persisted longest after the reversal.

(3.) To search for faint red lines below C in the spectrum of the chromosphere, and two faint green lines between $D_3$ and 1474 of the coronal spectrum.

(4.) To search for dark lines in the coronal spectrum.

I failed to detect at the beginning or the end of totality, the reversal of the Fraunhofer lines; at the beginning of totality they disappeared instantaneously, and the dazzling, continuous spectrum of the sun was as suddenly greatly diminished in brightness; at the same time the bright lines of the chromosphere made their appearance, lasting but a few seconds, when they disappeared gradually and simultaneously, with the exception of the line 1474. This increased steadily in brilliancy, while the continuous spectrum grew fainter. A few seconds after the disappearance of the chromospheric lines, a light cloud passed over the eclipsed sun, and after its passage I began my search for the phenomena I wished to observe. There was only the bright line, 1474, visible, and this was intensely brilliant. I was greatly perplexed by the absence of all other bright lines, and I searched for a long time in the red, yellow, and green, without taking note of the time, thinking the other coronal lines might be very faint. While engaged in this I detected what appeared at first to be faint dark lines in the orange red. This appearance of there being several lines, I am now inclined to ascribe to the fact that the line was very faint, and appeared only at intervals, disappearing and again reappearing in quick succession. This I saw several times during the first half of totality. As Mr. FLETCHER called out 190, I began to fear that the spectroscope slit might be too narrow, and widened it; after this I did not see the dark line.

As there continued to be visible only the one line, and as I had searched thoroughly for others, I began to experiment with the slit width, but succeeded in bringing out nothing else. While engaged in this I was greatly surprised by the reappearance of the bright lines of the chromosphere. In my anxiety I had ceased keeping track of the time, and at first mistook them for the other bright lines for which I was seeking. While comparing them one with another, in order to determine their relative magnitude, I observed a very faint red line a little less refrangible than C. But just at the time I picked up this line, I became aware of their true nature by hearing Mr. FLETCHER call out that the eclipse was over, so that I obtained only a momentary view of it. The lines visible at the time were *G** (which I did not examine closely); *F*, a very bright blue; 1474, a dazzling line in the green, but not so bright as it had been during mid-totality; $D_3$, a bright, yellowish-green line; C, a broad and very bright red line; just a little below C was the faint line of which I have spoken, and which, though very little brighter than the red of the continuous spectrum, was distinct from it.

As I thought at the time these lines were those of the coronal spectrum, I estimated their relative rightness in magnitude, as follows: 1474, 1; F, 1.5; C, 2; $D_3$, 3; G, ?.

They lasted between 20 and 25 seconds; Mr. FLETCHER had but shortly ceased calling out the time, and the end of totality took place 35 seconds after his last call.

II. Computation of contacts, and observed times of contacts.

Using the approximate position of Caroline Island (Lat. 10° 0′ 4″.30 South, Long. 150° 15′ 00″ West), I computed the times of contact as follows:

| | | | | |
|---|---|---|---|---|
| I. | $10^h$ | $3^m$ | $25^{sec}$ | L. M. T. |
| II. | 11 | 31 | 50.04. | |
| III. | 11 | 37 | 21.24. | |
| IV. | 1 | 10 | 33.?. | |

* This line is not G, but the line of hydrogen just below G.—E. S. H.

Position angle of contact:

| | |
|---|---|
| I. | 246° 53′. |
| II. | 46° 21′. |
| III. | 270° 14′. |
| IV. | 72° 27′. |

The observed times were as follows:*

CONTACT I.

| | *h.* | *m.* | *s.* |
|---|---|---|---|
| E. D. PRESTON; | 10 | 3 | 41.6 |
| W. UPTON; | .. | 3 | 38. |
| S. J. BROWN; | .. | 3 | 44.8 |
| P. TACCHINI; | .. | 3 | 18.4 |
| J. PALISA; | 10 | 3 | 33.6 (late). |

CONTACT II.

| | *h.* | *m.* | *s.* |
|---|---|---|---|
| E. D. PRESTON; | 11 | 31 | 54.1 |
| P. TACCHINI; | .. | 31 | 50.4 |
| J. PALISA; | .. | 31 | 53.2 |
| L. TROUVELOT; | 11 | 31 | 51.8 |

CONTACT III.

| | *h.* | *m.* | *s.* |
|---|---|---|---|
| E. D. PRESTON; | 11 | 37 | 18.7 |
| P. TACCHINI; | .. | 37 | 13.4 |
| L. TROUVELOT; | 11 | 37 | 15.8 |

*Duration of totality:*

| | *m.* | *s.* |
|---|---|---|
| PRESTON; | 5 | 24.6 |
| TACCHINI; | 5 | 23.4 |
| TROUVELOT; | 5 | 24.0 |

CONTACT IV.

| | *h.* | *m.* | *s.* |
|---|---|---|---|
| E. D. PRESTON; | 1 | 10 | 45.4 |
| E. S. HOLDEN; | .. | 10 | 43.8 |
| C. H. ROCKWELL; | .. | 10 | 45.6 |
| W. UPTON; | .. | 10 | 45.0 ? (seconds marked 35). |
| S. J. BROWN; | .. | 10 | 41.5 |
| P. TACCHINI; | .. | 10 | 48.4 |
| J. PALISA; | 1 | 10 | 35.2 |

For observing the I and IV contacts, I used the comet-seeker brought from the Observatory. Having no higher power than 21 belonging to that instrument, I fitted one from the 3-inch equatorial, which on this instrument gave a magnifying power of 37. The instrument is mounted equatorially on a brass standard of sufficient weight to secure steadiness. The dimensions of the telescope are as follows:

Clear aperture 4 inches; reduced to $1\frac{1}{2}$ inches by cap.

Focal length 42 inches.

Magnifying power of eye-piece 37.

For marking the time I used a sounder connected with the chronograph, which in turn was

* I have added to Mr. BROWN'S figures the results given in the Report of the French Eclipse Expedition. *Comptes Rendus*, 1883, September 3.—E. S. H.

connected with chronometer 1589 Negus. I observed the first contact at C. T. $1^h\ 0^m\ 35^s$. I am sure it was at least 5 seconds late, and so recorded immediately after marking the time.

| | I. | | | | IV. | | |
|---|---|---|---|---|---|---|---|
| | *h.* | *m.* | *s.* | | *h.* | *m.* | *s.* |
| C. T | 1 | 0 | 35.00 | | 4 | 8 | 1 |
| C. Cor | .. | .. | 29.64 | | .. | .. | 30.13 |
| L. S. T | 1 | 1 | 4.64 | | 4 | 8 | 31.13 |
| S. R. A | 2 | 53 | 42.37 | | 2 | 57 | 38.9 |
| Sid. Int | 22 | 7 | 22.27 | | 1 | 10 | 52.23 |
| Cor | .. | 3 | 37.45 | | .. | .. | 11.62 |
| L. M. T | 10 | 3 | 44.82 | 5 seconds late. | 1 | 10 | 40.61 |

### III.—Pendulum and latitude observations.

At the request of the Superintendent of the Coast and Geodetic Survey, Prof. J. E. Hilgard, I assisted Mr. Preston in the Pendulum Observations at Caroline Island. Mr. Preston in his report has given a full account of the instruments employed; I will only report concerning my share of the observations.

Before leaving Washington I received instructions at the Coast and Geodetic Survey office as to the methods: and assisted, during the week previous to leaving Washington, in the necessary preliminary observations at the Smithsonian Institution.

On Caroline Island I was busily engaged from the 22d to the 25th of April in unpacking and setting up the pendulum apparatus and assisting in setting up and adjusting the transit instrument. From the 25th to the 29th, inclusive, I observed pendulum transits from 7 p. m. until 5.30 a. m. the following morning. On April 30, May 1, 6, and 7, I observed from 7.30 p. m. to 2 a. m., Mr. Preston relieving me at that hour.

On May 4, 6, 7, and 8, in addition, I made observations with the reversible transit instrument for latitude. Mr. Preston has detailed in his report the difficulties encountered by warping and slacking of micrometer spider lines; the one he finally succeeded in getting taut enough having a diameter of 8″. In many of my observations for latitude I found it necessary to bisect stars off the middle thread, and accordingly I was obliged to determine the inclination of the micrometer thread. The manner and results will be found in Mr. Preston's report. I will only say in regard to my observations for latitude that, considering the difficulties under which they were made, I am more than pleased with the accordance of the results. I have made a preliminary reduction of 22 pairs which gave me a latitude of

$$S\ 10^\circ\ 0'\ 1''.30 \pm 0''.47$$

This I expect will not differ from the final, except in giving a somewhat larger probable error.

Respectfully,

S. J. BROWN,
*Ensign, U. S. N.*

### (*g.*) *REPORT OF LIEUT. E. F. QUALTROUGH, U. S. NAVY.*

U. S. Steamer Hartford,
*At Sea, May* 14, 1883.

Prof. Edward S. Holden,

*Chief of U. S. Eclipse Expedition to Caroline Island*, 1883:

Dear Sir: In accordance with your request, I volunteered to join the Eclipse Expedition, and to conduct the photographic observations, with the photoheliograph brought by Messrs. H. A. Lawrance and C. R. Woods, the English scientists sent out by the Royal Society of England.

After all preliminary arrangements had been made, I received orders from my commanding officer, Capt. C. C. CARPENTER, U. S. Navy, to assume the command of the officers and men landed to assist the Eclipse Expedition.

I have the honor to transmit to you herewith a report of the work done by me during the eclipse.

The instrument used by me consisted, essentially, of two photoheliographs, the tubes of which were equatorially mounted on a long iron pillar or stand. Mr. LAWRANCE has kindly supplied me with the following concise description of the apparatus.

This instrument was constructed by J. H. DALLMEYER, of London, England, for the purpose of taking photographs of the transit of Venus in 1874. The brass tube is mounted equatorially, and is driven by a clock regulated by a conical governor. The object glass is achromatic, with an aperture of 4 inches. The focal length is between 5 and 6 feet. The image is magnified to 4 inches in diameter by a secondary magnifier placed at the principal focus of the object glass. A long mahogany box, carrying at one end a rapid rectilinear lens, by DALLMEYER, with the back combination removed, and at the other end a $3\frac{3}{4}$ by $4\frac{1}{2}$ camera was designed to clamp to the brass tube. The focus of the object glass was about 5 feet.

Much trouble was experienced in arranging the various parts of the instrument, but the extraordinary efforts of Messrs. LAWRANCE and WOODS were crowned with success, and by persistent hard labor the photoheliograph was eventually set up and adjusted.

A strong pier of bricks and Portland cement was built and leveled very carefully, after which the iron pillar was placed upon the foundation so obtained. This pillar was in three parts, which were held together by iron bolts.

The brass tube was fixed in place with great difficulty, as the holes in the carrying plate were not in line with those in the straps encircling the tube, and it was therefore impossible to use the bolts to secure it. It became necessary to resort to lashings, and, accordingly, two strong copper wire seizings were passed around both tube and carrier plate, after which a strong lashing of white line was added to render the fastening as rigid as possible.

When it became desirable to affix the mahogany box to the brass tube, one of the blocks made to clamp around the tube was found in two peices, and it was necessary to secure this block also by a lashing of white line.

Owing to a lack of proper facilities, it was not an easy task to get the tubes parallel, and it was still more difficult to retain this adjustment when once obtained.

The method used by Mr. LAWRANCE to focus the instrument was the following:

1. A sharp image of the cross-wire at the principal focus of the object glass is obtained by moving the secondary magnifier.

2. The object glass was screwed in or out, until the image of the sun was brought to focus.

The parallelism of the tubes was renewed each day up to the day of the eclipse.

There was considerable vibration to the long brass tube, one cause of which appeared to be a lack of strength in the iron pillar, near the top, to resist torsional strain. Even the slight jar occasioned by entering or withdrawing a plate gave rise to a vibratory motion, and, although the trees gave great protection from the prevailing wind, a strong breeze caused the tube to tremble.

With a view to remedy this as much as possible, guys of heavy white line were set up to stakes driven into the earth, on either side of the pillar, and these guys were frapped together about one-fourth of the distance from the top, in which manner the whole system of stays was brought very taut. As an additional precaution the lashings and guys were wet about an hour before totality in order to bring them as rigid as possible at the time of the observations.

By great care and attention the clock was brought to perform well on Saturday, the 5th instant, but it required further adjustment on the morning of the 6th.

The photoheliograph was focused on Saturday, the 5th, by Messrs. LAWRANCE and WOODS, and the tubes were marked, circles read, and all made ready for the coming event.

Practice rehearsals were begun on May 1, and continued, at the rate of two or three each day, up to the day of the eclipse.

The morning of May 6 was somewhat unpropitious, as it was overcast and cloudy, and between eight and nine o'clock rain fell, but the weather began to clear afterwards, and although there were many clouds in the sky, a clear view of the eclipse was obtained at totality.

I gave the photoheliograph a final adjustment during the forenoon, and was at my post prepared for the work in hand some time before totality. The clock could not be brought to drive at an uniform rate of speed for any great interval of time, and consequently, after working with it up to the last ten minutes before second contact, I was compelled to use it performing only fairly.

In addition to the photoheliograph, it was at first intended to supply me with a small camera for making a single long exposure during totality, but, finding by a trial on the night of the 4th that no good result could be looked for, Mr. LAWRANCE withdrew it.

Special care was given by me to the manipulation of the plates during totality.

From the beginning to the end of totality I exposed six plates in the mahogany tube, and three plates in the larger, or brass tube, according to the following time-table, which was arranged by Mr. LAWRANCE:

TIME TABLE FOR PHOTOHELIOGRAPHS.

| Time in seconds. | Small photoheliograph. | Large photoheliograph. |
|---|---|---|
| Totality begins—300 | Expose 1 second ........ | Expose. |
| 290 | ........................ | |
| 280 | ........................ | |
| 270 | Expose ................. | |
| 260 | ........................ | |
| 250 | Close .................. | |
| 240 | ........................ | |
| 230 | ........................ | |
| 220 | ........................ | |
| 210 | Expose ................. | Close. |
| 200 | ........................ | |
| 190 | ........................ | Expose. |
| 180 | ........................ | |
| 170 | ........................ | |
| 160 | ........................ | |
| 150 | ........................ | |
| 140 | ........................ | |
| 130 | ........................ | |
| 120 | ........................ | |
| 110 | ........................ | |
| 100 | ........................ | |
| 90 | Close .................. | |
| 80 | ........................ | |
| 70 | Expose 3 seconds ....... | Close. |
| 60 | ........................ | |
| 50 | ........................ | |
| 40 | Expose ................. | Expose. |
| 30 | Close .................. | |
| 20 | ........................ | |
| 10 | Expose 2 seconds ....... | |
| 0 | ........................ | Close, before the end. |

The plates used in both tubes were very sensitive gelatine plates, prepared in Captain ABNEY's laboratory, at South Kensington, and after the eclipse they were developed by Mr. C. R. WOODS.

NAKED-EYE VIEW.

Before the beginning of totality and during its progress I had several opportunities of getting a naked eye view of the awe-inspiring phenomenon. As the eclipse advanced, the sky showed a peculiar coloring which gradually became darker. The trees, tents, etc., were also singularly tinted.

About the time of totality a moderate number of stars appeared, but the darkness was not so intense at any time during the eclipse as I had expected. I could see the camp and surrounding landscape, and noticed some frigate birds sailing about in the air. My lamp seemed to throw no additional light on the programme I had prepared, and I think I could have dispensed with any artificial light.

During totality the moon was surrounded by a beautiful halo of silvery light, its color reminding me somewhat of the electric light, and shining through or over this halo were long white streamers, which diverged ray-like from the edge of the moon's disc.

The sky immediately surrounding the sun and moon was of a dusky hue, darkest toward the bodies. This dark tint was disc-shaped and seemed to fade toward the outer boundary.

During the eclipse I was assisted by Seaman Gunner HORACE YEWELL, of the Hartford, and to his intelligent action much of the success attending my efforts is due. He also arranged the guys and lashings, and assisted in setting up the instruments.

Very respectfully,

EDWARD F. QUALTROUGH,
*Lieutenant United States Navy.*

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ADDENDUM TO THE REPORT OF LIEUTENANT QUALTROUGH, U. S. N.

U. S. S. HARTFORD, 2D RATE,
*At Sea, May* 23, 1883.

DEAR SIR: Mr. LAWRANCE having expressed a desire that some additional details concerning the handling of the plates should find a place in my report of the operations of the photoheliograph, I take pleasure in sending them herewith.

About forty minutes previous to totality, Mr. LAWRANCE brought the photographic plates to me, and remarked that he feared the six-inch plates were light-struck. I placed them under a waterproof blanket at once and kept them in total darkness until used.

Shortly before totality the clock was wound, and at ten minutes before second contact the sun was brought in the center of the screen of the large instrument. One minute before second contact the first plate holders were inserted, and screens were placed over the object glasses by YEWELL. As soon as the screens were in place I drew the slide, and, when the signal for totality was given, ordered YEWELL to remove the screens.

The exposures were made according to the table given in my report.

After the plates had been exposed they were carefully returned underneath the rubber blanket, and after totality were taken charge of by Mr. WOODS.

When the oriented plates were taken by Mr. WOODS about half an hour later, the sky was quite cloudy.

Very respectfully,

EDWARD F. QUALTROUGH,
*Lieutenant United States Navy.*

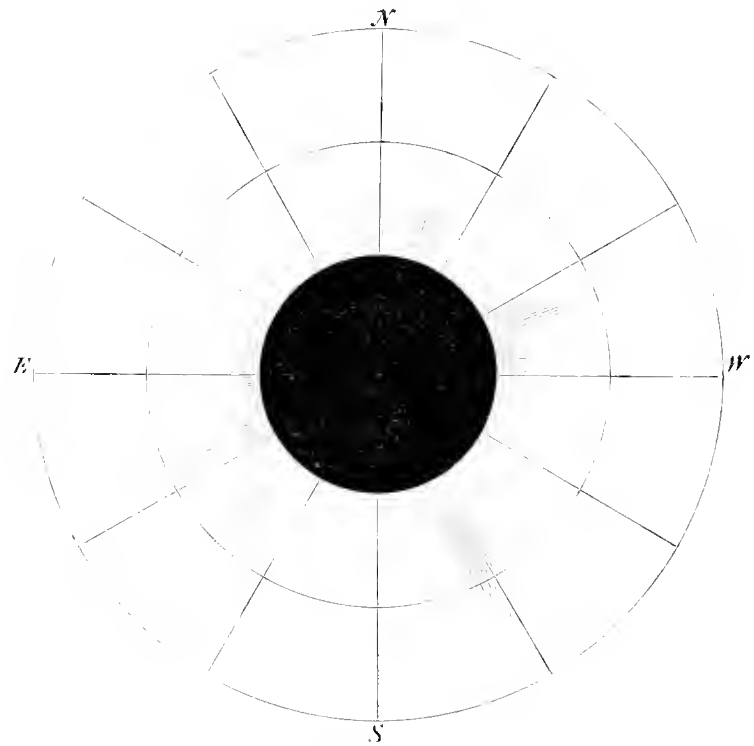



FIG. 22.—DRAWING OF THE CORONA, BY DR. W. S. DIXON.

(h.) *REPORT OF DR. W. S. DIXON, U. S. N.*

U. S. S. HARTFORD, *May* 7, 1883.

SIR: Agreeably to your instructions, I herewith submit the following report of my operations upon the day of eclipse, and of the observations made upon the fauna and flora of Caroline Island. The three partitions are respectively marked A, B, and C.*

Very respectfully,

WM. S. DIXON,
*P. A. Surgeon.*

Prof. E. S. HOLDEN.

OBSERVATIONS OF THE ECLIPSE.

The instrument used for observing the corona was a CLARK'S portable equatorial, 60 ± magnifying power and 3½ aperture.

The legs of the tripod stood firmly upon blocks driven in the ground, and the instrument was sufficiently steady for the work required. The definition was good. A diagonal eye-piece, with cross-wires arranged in the meridian and parallel, was used. The north point was at the apparent top of the field, and the west point at the apparent right hand.

A spectroscope, lashed to the tube, was used during the period of totality by Mr. S. J. BROWN.

Previous to totality I made notes and observed time for Mr. E. D. PRESTON.

Upon the first glimpse of the corona, I believed it possible to make a satisfactory representation of its structure; but, with the exception of two or three features, soon discovered that inexperience would prevent a complete delineation.

To the right of the spider line in the meridian, at the upper part of the corona, the first large tail of light was filamentous to a great extent, irregularly arranged, a majority of the fibers, however, assuming a curved direction trending to the right. Nearly, or quite all the fibers, were tinted a delicate lilac. An apparent movement among them seemed to be due to changes in the depth of color that continued as long as I dared devote to that particular portion of the spectacle. Just above the parallel wire on the right side, and extending one-fourth diameter from edge of moon, there were numerous narrow threads or fibers, apparently colorless, but having a more perceptible movement even than the fibers in the tail of light before mentioned. These threads, also, were irregularly arranged, some of them almost bowed, and presented the appearance exhibited by a wheat field during the prevalence of a strong wind.

About 125° from the meridian line above the moon there was a rift or dark streak on the left side that extended one-half diameter from edge of black disk. Ends of prominent tails split up into two or more acute points. Between the prominent tails of light there were numerous smaller ones, exceedingly narrow and acutely pointed, many being mere pencils of light, and all of homogeneous character. The two red prominences observed corresponded, approximately, to figures 1 and 5 on face of watch. The original copies and drawing are herewith appended.†

* The portions marked B and C have been given under the proper headings in section IV. of this report, and are not repeated here.—E. S. H.

† These have been carefully compared and the last copy (only) is reproduced here.—E. S. H.

(i.) *REPORT OF MIDSHIPMAN W. B. FLETCHER, U. S. N.*

U. S. S. HARTFORD, SECOND RATE,
*At Sea, May* 19, 1883.

SIR: The following is the report of my time-counting during the total eclipse of the sun of May 6, 1883.

The chronometer used was "Hutton" No. 202, keeping local sidereal time; chronometer error, slow 9.5 seconds. The chronometer time, ten minutes before the time by computation of second contact, was $2^h\ 18^m\ 58^s$. At this time I commenced and called out each minute, 10, 9, 8, 7, &c., to 1. From $1^m$ every ten seconds, 50, 40, &c., to 0.

I then marked the time of second contact, observed by Mr. E. D. PRESTON, of the United States Coast and Geodetic Survey, which was $2^h\ 29^m\ 19^s$, and ten seconds thereafter called out 290, and each succeeding ten seconds, 280, 270, 260, &c., to 0. Then I marked the time of third contact, which was $2^h\ 34^m\ 44.5^s$, and called out each interval of ten seconds up to $1^m$, then each minute up to ten minutes.

In addition to this I marked the times of first and fourth contacts, observed by Mr. W. UPTON, United States Army Signal Office.

During the remainder of the time on the island I was engaged about six and one-half days in the field-work of a survey of the island, and three and one-half days in plotting the survey, under the direction of Lieut. E. F. QUALTROUGH, U. S. N.

Very respectfully,

W. B. FLETCHER,
*Naval Cadet, U. S. N.*

Prof. EDWARD S. HOLDEN,
*In Charge of U. S. Eclipse Expedition.*

(j.) *REPORT OF MIDSHIPMAN DOYLE, U. S. N.*

U. S. S. HARTFORD, SECOND RATE,
*At Sea, May* 19, 1883.

SIR: The following is a report of my pointing of M. E. D. PRESTON'S telescope during the eclipse of May 6, 1883. The pointings began and ended with totality; during which time I pointed the telescope at eleven different parts of the corona. The situation of these points is shown on the diagrams accompanying this report. No. 1 (omitted) is my original; No. 2, a copy. I attended all rehearsals and practiced at pointing the telescope at different places, and at estimating distances in terms of the sun's diameter. In addition to the above, I assisted Lieut. E. F. QUALTROUGH, U. S. N., to make a survey of Caroline Island.

Very respectfully,

JAS. G. DOYLE,
*Naval Cadet, U. S. N.*

Prof. EDWARD S. HOLDEN,
*In Charge of U. S. Eclipse Expedition.*

(k). *MEMORANDUM IN REGARD TO THE PHOTOGRAPHIC OBSERVATIONS OF THE ECLIPSE.*

[NOTE.—The following memorandum in regard to the instruments and results of the English party has been kindly handed to me by Mr. H. A. LAWRANCE at my request.—E. S. H.]

The English party consisted of two observers, Mr. H. AUBREY LAWRANCE, F. C. S., assistant to the committee on Solar Physics, and Mr. C. RAY WOODS, of the Normal School of Science, South

Kensington, formerly assistant to Captain ABNEY, R. E. The instruments under the charge of Mr. WOODS were not pointed directly to the sun but placed horizontally, the light being reflected to them by a siderostat made by COOKE for the Royal Society, possessing a 12-inch plane silver on glass reflector. Four instruments were used in connection with it, and were arranged thus:

1. An integrating spectroscope made by HILGER, with a long collimator of 3° angular aperture, and 4½ feet focus, with one large white glass prism and DALLMEYER lens of three-inch aperture, throwing an image on to a plate placed at a considerable angle by means of an extra swing back. The instrument was adjusted with F in the center of the field, and the photographic plate was moved regularly across the opening by means of clock-work.

2. To the left of number one was placed a slit spectroscope for photographing the spectrum of the corona, the image of the latter being projected on the slit. Two prisms and a camera of short focus were used, only one plate being exposed throughout totality. This instrument is the same that was successfully used at Sohag last year, with this exception, that only one prism was used on the previous occasion.

3. To the right of number one was placed a prismatic camera with a lens of about 24 inches focal length and about 2¼ inch aperture, and a white glass prism of 60°. It was adjusted with F in the center of the plate, as in Egypt, when a successful result was obtained from the blue to the red end.

4. On top of the three preceding instruments was placed a ROWLAND grating, which was adjusted for parallel rays. Two cameras were attached to it, one of them taking in about 6° of the first order, with F in the center of the field, and the other embracing about 6° of the second order on the same side, with H in the center of the field. The result desired in this instrument was the ring spectrum more widely dispersed than the prismatic camera would give it.

The integrating spectroscope gave a satisfactory result, photographing prominent lines in the reversion spectrum at the beginning and end of totality. The slit spectroscope, for the corona, was also very satisfactory, a good photograph of the coronal spectrum from the ultra violet to the green being obtained. The spectrum was mainly continuous with a number of bright lines. Good photographs were also obtained with the prismatic camera, but the faintness of the comparatively few rings that were visible during this eclipse render the results less striking than the result obtained in 1882. Bearing this in mind, no surprise will be occasioned at the failure of the ROWLAND grating. Had such a series of rings appeared as were seen in 1882 a satisfactory result would probably have been obtained. Mr. LAWRANCE had a 6-inch achromatic telescope, equatorially mounted by COOKE of York, driven by clock-work. Attached to it was a RUTHERFORD grating, 17,000 lines to the inch, mounted by ADAM HILGER, of 1 Mornington Crescent, London, at a few hours' notice. On each side of the grating was a camera, with lenses by DALLMEYER, one pointing to the first and the other to the second order.

Clamped to this telescope was a 6-inch rapid rectilinear photographic lens, by DALLMEYER, of about 4 feet focus. This lens was provided with a slit spectroscope, with a dense yellow-glass prism, which gave a well-dispersed image on the camera screen.

In each of these three cameras the F line was in the middle of the plate.

All the cameras were made by PHILIP MEAGHER, and these three and the two used with the ROWLAND grating were provided with an arrangement whereby the sensitive plate was moved by a rack and pinion across the image of the spectrum, thus saving a great deal of time which would otherwise have been lost in changing plates.

Mr. LAWRANCE started taking photographs ten minutes before and continued doing so till ten minutes after totality. He was successful in obtaining some of the bright lines before and after totality in the first-order spectrum and prismatic spectrum, and the second-order spectrum may show something when examined under suitable conditions.

During totality he examined the sun with a direct-vision prism. He saw the 1474 ring very bright and strong and C and $D_3$ very faint, no trace of F, and a lot of continuous spectrum. Last year in Egypt, with the same instrument, he saw C, F, and $D_3$ very bright and 1474 faint.

A photoheliograph that the English party brought with them was used by Lieutenant QUALTROUGH, who obtained some very successful pictures.

Messrs. LAWRANCE and WOODS state that the general appearance of the corona was very like that of last year, and very much more brilliant than they anticipated it would be.

NATIONAL ACADEMY OF SCIENCES.

# SECOND MEMOIR.

# EXPERIMENTAL DETERMINATION OF WAVE-LENGTHS

IN THE

# INVISIBLE PRISMATIC SPECTRUM.

BY

PROF. S. P. LANGLEY.

# EXPERIMENTAL DETERMINATION OF WAVE-LENGTHS IN THE INVISIBLE PRISMATIC SPECTRUM.

*A COMMUNICATION TO THE NATIONAL ACADEMY OF SCIENCES, IN APRIL, 1883.*

[NOTE.—The following investigation was made at the expense of the Bache fund and is published here by the permission of its trustees.]

In September, 1881, while engaged upon Mount Whitney in measuring with a linear bolometer the heat in the invisible spectrum of a flint prism, I came upon a hitherto unknown cold band whose deviation indicated a (probably) very great wave-length.* We have had up to the present time no way of measuring such wave-lengths directly, but are accustomed to determine them by more or less trustworthy extrapolation formulæ, the best known of which is CAUCHY'S. Accordingly, I attempted to calculate the wave-length by CAUCHY'S formula, but was conducted to an impossible result—the formula declaring that no such index of refraction as I had measured was possible in the prism in question. But the measurement was a fact beyond dispute, and this drew my attention to the grossness of the errors to which the customary formulæ may lead.

Every prism gives a different map of the spectrum, nor when we find a band or line by the prism have we any means of fixing the absolute place, except by a reference to the normal or wave-length scale, or to one derived from it.

It is desirable to define at the outset the sense in which the term "normal" is here used, as a synonym for "wave-length" spectrum.

The amount of energy in any region of the spectrum, such as that in any color, or between any two specified limits, is a definite quantity, fixed by facts which are independent of our choice, such as the nature of the radiant body, or the absorption which the ray has undergone. Beyond this, nature has no law which *must* govern us in representing the distribution of the energy, and all maps and charts of it are conventions.

If the length of the spectra formed by any two different agents, such as a prism and a grating, be made equal, it does not then follow that the lengths of similar portions must be equal. In the case supposed, we observe in fact that the red portion (for instance) of the prismatic spectrum will be narrower than the red portion of the second. But since the amount of energy in the red must be really the same in both, we must, in a graphic representation of this energy, increase the height of the ordinates in the red of the prismatic spectrum, so that the areas shall remain the same.

The position of the maximum ordinate is then (in one sense), a matter of choice, and fixed only by the scale we elect to employ. We find, for instance, in the prismatic spectrum, that this ordinate is in some part of the infra-red, depending on the particular prism used; while, in the grating spectrum, it is, under the same circumstances, always in one part of the yellow; and we might conceive of an apparatus which should always exhibit it in the ultra-violet, or which should even show the same energy at one wave-length as at any other, or embody any other arbitrary

* Since designated as "Ω."

mental picture of it. It is certainly a practical consideration of the first importance that no such apparatus actually exists; but still, whether it exist or not, in so representing the distribution of energy, we should break no law except that imposed by considerations of simplicity and convenience.

Did the word "normal," then, signify "absolute," there would be no spectrum, exclusively entitled to such a name; but, in this connection, the word is always to be understood in its radical meaning of an accepted rule or type of construction. Such a type exists in the wave-length spectrum; and it has obtained general acceptance, not only on account of its simplicity and convenience, but of its, at present, unique claim to be a "natural" one. It is properly distinguished as the "natural" scale from its not merely representing a mental picture of the distribution of the energy, under a very simple law, but of actually being that which we do produce by our most efficient optical apparatus, and make visible and measurable at will.

While we remain at liberty, then, to represent the energy spectrum in terms of the wave frequency, or of the reciprocal of the square of the wave-length, or of any other function of it, and while we may often find occasion to use these scales for some special purposes, we are (and all the more especially that we habitually speak in terms of the wave-length) led by considerations of a very practical kind to take as our normal or standard scale that of the wave-length itself.

Since we have this normal spectrum actually before us, through the concave gratings constructed by Professor ROWLAND, it may seem as though we might dispense with the prism; but this is not as yet possible for the lower part of the spectrum, where overlapping spectra and feeble heat make the use of the grating too difficult. If we could use the solar energy here, not in the form of heat, but of chemical action, as in photography, a great advance might be made; and there is reason, I believe, to hope that the labors of Professor ROWLAND and Captain ABNEY will ere long do this for us with precision. At present, however, we have only heat, and the thermopile or the bolometer; which latter, though less sensitive than the camera, can be made, as I shall show, to determine experimentally, within known limits of error, the actual wave-lengths corresponding to given indices of refraction, and hence to afford here valid experimental data for passing from the prismatic spectrum to the normal one. The reason why this so desirable information has never been obtained before is two-fold: (1) While the measurement in question can best be made by means of a prism and grating conjointly, the heat, which in the lower prismatic spectrum is very faint, becomes almost a vanishing quantity when it has passed the grating also, where the heat is on the average less than one-tenth that from the prism. We must use too, if possible, a narrow aperture to register this heat; for a broad one might (on account of the compression of the infra-red by the prism) cover the whole field in which its work should be to discriminate. (2) We must have not only an instrument more sensitive than the common thermopile, but we must devise some way of fixing, with an approximate precision, the point at which we are measuring when that point is actually invisible.

The apparatus I have devised for this double purpose has done its work with a degree of accuracy, which if it may be called considerable, as compared with what we have been used to in heat measurements, is yet necessarily inferior to that obtained by the eye, and less than we may hope for at some future time, from photography. Nevertheless it has, I believe, given experimental data very far outside the visible spectrum, by which we may either construct an empirical formula and supply its proper constants so that it will be trustworthy within extended limits, or test the exactness of such formulæ as CAUCHY'S, REDTENBACHER'S, &c., which, while professing a theoretical basis, only agree in their results within the limits of the visible spectrum (from which they have been in fact derived, and where they are comparatively unneeded). They contradict each other, as will be seen, as soon as they are called on for information, in the region outside of it, where they would be chiefly useful.

The present work has been preceded by a new map of the invisible prismatic spectrum, where the abscissæ were proportional to the deviations in a certain prism. (See Comptes Rendus de l'Academie des Sciences Sep. 11, 1882, and Am. Jour. of Science, Vol. XXVI, Plate III.) And the immediate object of this research is to pass from the arbitrarily spaced prismatic scale belonging to the particular prism in question, to the present map on the normal and absolutely general one (Plate XII), which was indeed also presented in the same journals, but in advance of the present detailed description of the means used to obtain it. (The drawings referred to are here given in detail in Plate XII.)

I should perhaps make the cautionary remark, that the general conclusions here offered, as to the relation of wave-lengths and indices of refraction, have been drawn from the observations on a single prism and have not been experimentally verified on others. This is on account of the extremely slow and laborious character of the process used (which has involved some months of labor for this special prism). Though there seems no reason to doubt the generality of our conclusions, it may be hoped that these experiments will be repeated with prisms of other material, and by other observers, now that the preliminary obstacles have been removed.

In order to map the spectrum on the normal scale, where the wave-lengths are equally spaced, from such a map as that shown in Plate XII, in which the consideration of wave-lengths does not enter, it is necessary to establish some relation between the wave-lengths of rays and their deviations, or between their wave-lengths and refractive indices, which are connected with the deviations by the well-known formula

$$n = \frac{\sin \frac{(a+d)}{2}}{\sin \frac{a}{2}},$$

where $a$ = the refracting angle of the prism, $d$ = the deviation, and $n$ = the corresponding index of refraction. In the visible spectrum, the deviation, in any prism, of the Fraunhofer lines (whose wave-lengths have been very accurately determined) can be measured by means of an eye-piece with cross-wires; and, from a sufficient number of such measurements, by making ordinates proportional to indices of refraction (or deviations) and abscissæ proportional to wave-lengths, a curve may be found whose equation is $n = (\varphi)\,\lambda$ or $d = (\varphi)\,\lambda$, representing the required relation to any degree of exactness.

In the invisible spectrum the difficulties are immensely greater and demand special means, not only on account of this invisibility, but owing to the absorption by the prism and to its compressing the rays.

The prism here used was made by Adam Hilger, of London, and its optical properties are in every way satisfactory. It is of a white flint, which has proved singularly transparent to the longest solar waves. Its principal constants are:

(1) Size of polished faces, $53^{mm}$ by $49^{mm}$.

(2) Specific gravity, 3.25.

(3) Refracting angle, $62^\circ\ 34'\ 43''$.

(4) Index of refraction (given in Table III).

### APPARATUS FOR MEASURING OBSCURE WAVE-LENGTHS.

In 1882 an apparatus was employed in which invisible rays, after passing through the HILGER prism, at a known deviation, fell on a RUTHERFURD reflecting grating (either of 681 lines to the millimeter or half that number) from which the diffracted invisible ray fell on the bolometer at a measured angle with the grating. By the use of the known formula ($ns\,\lambda = sin\ i + sin\ r$), connecting the angle of diffraction with the wave-length, the wave-length was then found.

Several determinations were thus made of wave-lengths in the upper part of the infra-red, where the heat is relatively great; but, though the definition of the RUTHERFURD grating was admirable, it was not large enough to supply sufficient heat to enable measures in the lower infra-red to be made with confidence.

In May, 1882, I had the good fortune to secure one of the very large concave gratings, then newly constructed by Professor ROWLAND, and which he was kind enough to make for me of a very short focus, so as to give a specially hot spectrum. After many essays, during which a great number of mechanical and optical arrangements for getting rid of the superposed spectra were tried with unsatisfactory results, it became clear that, for this large and concave grating, it was necessary to let the ray fall first on it and then on the prism, thus making the wave-length the known and the deviation the unknown quantity.

In the use of this form of grating, the slit is placed in the circumference of a circle whose diameter is equal to the radius of curvature of the grating and which touches its surface. The spectra are then formed, without the need of collimator, observing telescope, or any further apparatus, all lying upon the circumference of the circle which contains the slit. The grating which was employed contains 18,050 lines, 142 to the millimeter (3,610 per inch), ruled on the surface of a concave mirror of speculum metal of $1^{m}.63$ (64 inches) radius of curvature, and exposes a ruled surface of $129^{cm}$ (20 square inches). By this large surface a spectrum is produced sufficiently hot, even in its lower wave-lengths, to affect the bolometer strips after the various reflections and absorptions to which the heat is necessarily subjected in passing through the apparatus.

Figure 1 illustrates the means finally adopted and the course of the rays through the apparatus; although, for the sake of distinctness, the mechanical devices used to maintain the proper arrangements of the parts are omitted. The rays of light, coming from the 12-inch flat mirror of the large siderostat, pass across the apparatus, and fall upon a 7-inch concave speculum at M, by which at a distance of about 5 feet they are converged to a focus at $S_1$. At this point is a vertical slit, adjustable to any desired width by a double screw, which moves both jaws at once, so as to keep the center always in the same place. This slit is protected from the great heat by a plate of iron pierced with an aperture only a little larger than the slit when open to the usual width. Beyond $S_1$ the rays diverge and fall upon the concave grating, G. Directly opposite the grating is a second slit, $S_2$, also double acting, and the apparatus is so arranged, that the two slits, $S_1$, $S_2$, and the grating, G, always lie upon the circumference of a circle whose diameter is 64 inches; and therefore in whatever manner the slits may be placed, the light coming through $S_1$ forms a sharp spectrum upon $S_2$. A very massive arm, carrying the grating, the slit $S_2$, and the heavy spectro-bolometer, is pivoted at the center of the circle, so that the relative positions of these parts are unchanged. The slit $S_2$ is automatically kept diametrically opposite the grating, and on the normal to its center.

The slit $S_2$ is the slit of the spectro-bolometer, provided with the same attachments as when used for mapping the visible spectrum (except that it is now fitted with simple collimating and objective lenses of the same special kind of diathermanous glass as the prism, instead of its own concave mirror). Its eye-piece and the bolometer are interchangeable.

By means of the eye-piece and graduated circle, the deviation, and consequently the refractive index of the rays passing through the slit can be determined, if they are visible. If they are invisible, their exact wave-length is known by a simple ocular observation of the visible ones, on

Fig. 1.

COURSE OF RAYS THROUGH APPARATUS IN THE DETERMINATION OF LENGTHS OF WAVES OF OBSCURE HEAT.

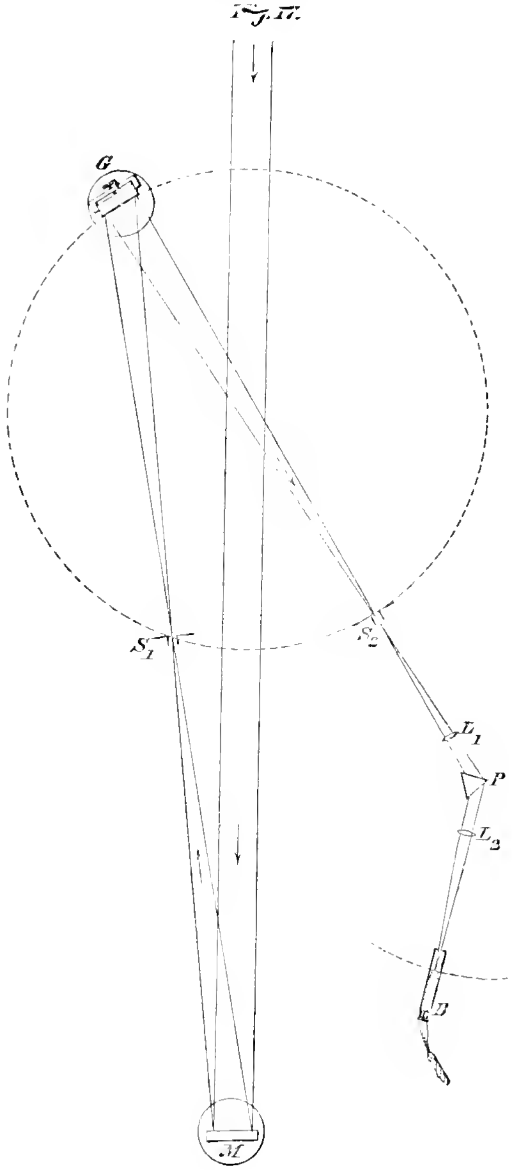
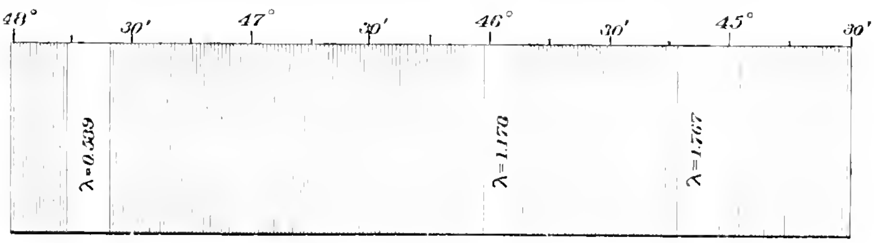


Fig. 2.

SPECTRUM FORMED BY PRISM IN DETERMINATION OF WAVE-LENGTHS.



which they are superposed by the action of the grating, while their subsequent deviation is determinable by the bolometer placed at B, provided they retain sufficient energy to affect the instrument. It will be seen that, according to this method, all those invisible rays, which are $n$ times the definitely known length of some visible ray, are caused to pass together through a slit, and then through a prism, which sorts out the ray of the first spectrum from that of the second; that of the second from that of the third; and so on, so that the corresponding index of refraction may be determined by observation; with the eye in the case of the visible, with the bolometer in that of the invisible ray.

To illustrate the use of the above described apparatus under somewhat unfavorable circumstances, let us consider as an example the observations of June 13, 1882, which were taken far down in the spectrum, where the heat is feeble, and the galvanometer deflection small, requiring a widely open slit. The apparatus having been previously adjusted, and the sunlight properly directed by the siderostat, the visible Fraunhofer line $D_1$, of the third spectrum of the grating, was caused to fall upon the slit $S_2$ of the spectro-bolometer. Then, according to the theory of the grating, there passed, through this slit, rays having the wave-lengths—

$0\mu.589$ (3d spectrum—*visible.*)
$1\mu.178$ (2d spectrum—*invisible.*)
$1\mu.767$ (1st spectrum—*invisible.*)

The prism having been removed, and the telescope brought into line, an image of $S_2$, of the same size as the slit itself, was formed in the focus of the object lens, and on testing with the bolometer, whose face was covered with a cardboard screen pierced centrally with a $2^{mm}$ slit, the heat of this image produced a deflection of the galvanometer needle of about 30 divisions. The prism was then replaced on the automatic holder and set to minimum deviation, and the image of the slit, containing superposed rays whose combined effect had produced the deflection just mentioned, was separated into three similar images* (fig. 2) each composed of nearly homogeneous rays. Of these three bands, only the first or most refrangible, containing the $D_1$ line, was visible, and its deviation was found to be 47° 41′, agreeing with the value given by the table. It was the object of the experiment to find the place of the lower invisible band, by groping for it; *i. e.*, to determine its deviation by trials with the bolometer at intervals sufficiently close to avoid the possibility of missing it altogether. According to BRIOT's formula, the deviation should be 45° 21′, and in the preliminary search the circle was accordingly set to this reading. Beginning at this point, and exposing the bolometer at every five minutes of deviation, it was found that the maximum effect was obtained nearer 45° 15′. The approximate position having thus been found, the slit $S_1$ was narrowed to $2^{mm}$, and the following measurements taken, the horizontal line giving the mean results of a series of thirty exposures of the bolometer, as it moved through the spectrum

TABLE 1.—*Determination of the refrangibility of feeble heat rays.*

| | | | | | |
|---|---|---|---|---|---|
| Prismatic deviation .................. | 45° 02′ | 45° 07′ | 45° 10′ | 45° 15′ | 45° 20′ |
| Means of galvanometer readings.... | 4.6 | 5.6 | 6.0 | 5.8 | 3.7 |

The maximum reading at 45° 10′ corresponds to a coincidence of the $2^{mm}$ bolometer aperture with the $2^{mm}$ invisible image of the slit, whose position is sought. From a subsidiary curve drawn through the points whose co-ordinates are, respectively ($x = 45° 02′$, $y = 4.6$), ($x = 45° 07′$, $y = 5.6$),

*These three images, being composed of rays of different wave-lengths, could not all be in the same focus of the same lens at the same time, since the collimator and objective of this spectrometer were simple lenses. The lenses were adjusted by means of a table of focal distances previously prepared, so as to throw a sharp (invisible) image of the band to be detected.

($x = 45°\ 10'$, $y = 6.0$), &c., it was concluded that the deviation of rays whose wave-length is 1.767 is 45° 10′: and each point in this determination being obtained from the mean of five observations the result is partly free from irregularities caused by changes in the state of the sky, and minute instrumental variations from extraneous causes, which here become of great relative importance, owing to the feeble heat measured.

Subsequent determinations, like the preceding, gave for the deviation of the same ray 45° 06′ and 45° 07′, and from a consideration of all, the deviation adopted was (instead of 45° 21′, as given by BRIOT's formula) 45° 08′, corresponding to a refractive index of 1.5549

By means of measurements like the one described above, the deviations of various obscure rays of known wave-lengths were determined. The indices of refraction were then computed by the usual formula

$$n = \frac{\frac{1}{2}\ (a + d)}{\sin \frac{1}{2}\, a}$$

where

$$a = 62°\ 34'\ 43''.$$

The results are contained in the following table, where, however, only the results of successful days are given, most of the observations having been lost through changes of the sky during the course of one determination.*

TABLE 11.—*Experimental determination of d or n as a function of λ (Hilger prism).*

| Date of observation. | $\lambda$ | $d$ | $n$ |
|---|---|---|---|
| April 1, 1882 | $1\mu.010 \pm 0.0053$ | 46° 12′ | 1.5654 |
| April 9 | $1\mu.200 \pm 0.0069$ | 45° 54′ | 1.5625 |
| June 27 | $1\mu.658 \pm 0.0091$ | 45° 16′ | 1.5562 |
| June 13-27 | $1\mu.767 \pm 0.0094$ | 45° 08′ | 1.5549 |
| July 14 | $2\mu.090 \pm 0.0104$ | 44° 45′ | 1.5511 |
| June 7 | $2\mu.356 \pm 0.0110$ | 44° 25′ | 1.5478 |

We observe that where measures are taken in the prismatic spectrum alone, we can generally use with advantage a bolometer of as small an aperture as one-fifth of a millimeter, but that here it is advisable to open it to 2mm, owing to the relative expansion of the spectrum and to the very feeble heat.

Owing to the difficulties arising from the almost infinitesimal amount of heat in question, numerous subsidiary observations are requisite for a single determination, which it therefore takes long to make, each final value resting upon between 20 and 100 readings. If it should possibly appear to the reader that in the three months of consecutive labor which were given to this part of the work, more than six points might have been determined in the curve, he is asked to remember that what is here difficult has till now been impossible.

Plotting the points given by the data in Table 11, and drawing a smooth curve through them, we obtain the curve of "observation," showing $n$ as a function of $\lambda$ in the lower curve of Plate 2 and $d$ as a function of $\lambda$ in the curve of Fig. 3, where the points obtained by observation are distinguished by small circles.

There would be no gain in accuracy at this stage in attempting to work from a formula representing the equation of the curve obtained, as the graphical construction is fully as trustworthy

*All these observations for discovering the relation between $n$ and $\lambda$ can be conducted with at least as much advantage by a powerful and constant electric light as by sunlight. The latter only, however, was at the observer's actual command.

as the data. This I say with special reference to the large original charts* which have been drawn by Mr. J. E. KEELER, of this observatory, and which seem to me favorable specimens of the accuracy obtainable by this method.

*We are now prepared to test the accuracy of the various formulæ connecting refraction with wave-length*, though it will be convenient to first prepare a table showing what this relation is in the visible part of the spectrum of the prism employed.

In the following table the deviations in the visible spectrum were measured by the spectrometer, reading to 10″ of arc, which has been already described, in which for this special purpose the bolometer was replaced by an achromatic observing telescope with a micrometer eye-piece, and the indices of refraction were computed by the usual formula. O in the ultra-violet was measured by the aid of a SORET fluorescent eye-piece, and its wave-length is from CORNU. The other wave-lengths are taken from ANGSTRÖM, but the unit is here the micron = .001 millimeter = (10,000 times the unit of ANGSTRÖM'S scale). $\lambda$ is here the symbol for the wave-length.

The following indices in the visible spectrum, on which the computations for testing the formulæ are founded, are trustworthy to the fourth decimal place here given.

TABLE III.—*Observed indices in visible spectrum of Hilger prism.*

| | $\lambda$ | $d$ | $n$ |
|---|---|---|---|
| *Line* A | 0μ.76009 | 46 49 05 | 1.5714 |
| C | 0μ.65618 | 47 15 45 | 1.5757 |
| $D_1$ | 0μ.58890 | 47 45 15″ | 1.5798 |
| $b_4$ | 0μ.51667 | 48 21 05″ | 1.5862 |
| F | 0μ.48606 | 48 11 15 | 1.5899 |
| $H_1$ | 0μ.39679 | 50 34 05″ | 1.6070 |
| O | 0μ.34400 | 52 43′ 00″ | 1.6266 |

A smooth curve drawn through points whose positions are given by the above table, represents with accuracy the relation between $n$ and $\lambda$ in the visible part of the spectrum. This method is, however, obviously inapplicable to the very extended invisible portion below the A line, and accordingly attempts were first made to effect the determination of corresponding indices and wave-lengths by extending the curve derived from the above observations by means of formulæ. Several formulæ have, it will be remembered, been proposed by physicists, expressing $n$ as a function of $\lambda$, and containing constants which are to be determined by observation, but it has never hitherto been possible to test these formulæ far from the visible spectrum, whence their constants have been in fact derived. This desirable test we are now prepared to apply.

The simplest as well as the most widely used formula is that of CAUCHY, which, as it is commonly written,

$$\left(n = a + \frac{b}{\lambda^2} + \frac{c}{\lambda^4}\right),$$

contains three unknown quantities, requiring for their determination three simultaneous equations. Selecting the lines A, D, and H for this purpose, we have from the table just given, the three equations,

$$1.5714 = a + \frac{b}{(0.76009)^2} + \frac{c}{(0.76009)^4}$$

* These original charts were exhibited to the members of the National Academy of Sciences, at Washington, in April, 1883. The engraving here given in illustration being on a much reduced scale, will merely indicate the exactness of interpolation possible by the originals.

$$1.5798 = a + \frac{b}{(0.58890)^2} + \frac{c}{(0.58890)^4}$$

$$1.6070 = a + \frac{b}{(0.39679)^2} + \frac{c}{(0.39679)^4}$$

from which by elimination

$$a = 1.5593 \qquad b = 0.006775 \qquad c = 0.0001137$$

so that for this prism, the formula becomes,

$$n = 1.15593 + \frac{0.006775}{\lambda^2} + \frac{0.0001137}{\lambda^4}$$

which we find on trial satisfies the observations in the visible part of the spectrum within very narrow limits. When, however, we attempt to extend the application of the formula to the infra-red region, its results are not so satisfactory. Since $b$ and $c$ are both positive, the least value which $n$ can have in our prism, according to the formula, is $a$, or 1.5593, corresponding to a deviation of 45° 35′, whereas the bolometric measurements show that in this prism the solar spectrum after absorption extends as low as 44°, with every sign that if it do not extend yet further, it is not on account of the prism, but because below this point the heat is absorbed by some ingredient of our atmosphere.

We conclude, then, that CAUCHY's formula gives grossly erroneous results when extended far behind the limits within which the observations on which it is founded are made. Its implicit assertion, that the lower limit of the prismatic spectrum (however great the wave-length of the ray transmitted) is not so far below A as A is below D, is absolutely contradicted by these experiments, and all extrapolations made by it, far from the visible spectrum in which its constants have been determined, are wholly untrustworthy, as will appear more fully later.

REDTENBACHER proposes the formula

$$\frac{1}{n^2} = a + b\lambda^2 + \frac{c}{\lambda^2}$$

for expressing the same relation. Using the same lines as before for determining the unknown constants, we have for the HILGER prism

$$\frac{1}{n^2} = 0.412297 - 0.00093711\lambda^2 - \frac{0.0039220}{\lambda^2}$$

a formula which also satisfies the observations in the visible spectrum, but fails when extended to the invisible. The curve representing it has a minimum point corresponding to $n = 1.5647$ for a value of $\lambda$ found from the equation $\lambda^4 = \frac{c}{b}$, or in the special case of the formula above, where $\frac{c}{b}$ is positive, $\lambda = 1.430$; so that for every value of $n$ greater than 1.5647, there are two real values of $\lambda$. This formula therefore is even less satisfactory than that of CAUCHY.

BRIOT gives a formula which has been asserted by other investigators* to represent satisfactorily the results of observation throughout the whole spectrum, namely:

$$\frac{1}{n^2} = a + b\left(\frac{n^2}{\lambda^2}\right) + c\left(\frac{n^4}{\lambda^4}\right) + k\left(\frac{\lambda^2}{n^2}\right)$$

From four equations like this, using values of $n$ and $\lambda$ corresponding to the Fraunhofer lines A, C, F, and H, the values of the constants were determined† as follows:

$$a = 0.41028 \qquad b = -0.0013495 \qquad c = -0.000003379 \qquad k = +0.0022329$$

* MOUTON, Comptes Rendus, vol. lxxxix, p. 291, and vol. lxxxiii, p. 1190.

† This formula has the practical inconvenience of leading to cubic equations, either in $n^2$ or $\lambda^2$, the solution of which is so tedious as to forbid its use where many places are to be independently found. I have been aided in the present lengthy numerical computations by Professor M. B. GOFF.

With the aid of these constants, the wave-lengths corresponding to given refractive indices were computed, and a curve representing the formula was plotted. This curve, as well as those representing CAUCHY's and REDTENBACHER's formulæ, is shown in Plate XIX, where we may obtain by simple inspection the actual errors of all the formulæ in question, or we may take them from the following table, whose results, I hope, will sipply useful data for those who are interested in theories of dispersion.

TABLE IV.—*Approximate errors in wave-lengths by Briot's, Cauchy's and Redtenbacher's formulæ for cold bands in infra red.*

[Comparison of theories with observation.]

| $n$ By obs. | Observed $\lambda$ | Wave-lengths derived by extra-polation. From Briot's formula. | | Fro formula. | | From Redtenbacher's formula. | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Value. | Error. | Value. | Error. | Value. | Error. | Value. | Error. |
| 1.5714 | 0.760 | 0.760 | 0.000 | 0.760 | 0.000 | 0.760 | 0.000 | | |
| 1.5697 | 0.815 | 0.815 | 0.000 | 0.818 | 0.003 | 0.820 | 0.005 | | |
| 1.5687 | 0.850 | 0.850 | 0.000 | 0.853 | 0.003 | 0.862 | 0.012 | | |
| 1.5678 | 0.890 | 0.891 | 0.001 | 0.900 | 0.010 | 0.915 | 0.025 | 2.230 | 1.340 |
| 1.5674 | 0.910 | 0.911 | 0.001 | 0.920 | 0.010 | 0.941 | 0.031 | 2.170 | 1.260 |
| 1.5668 | 0.940 | 0.942 | 0.002 | 0.960 | 0.020 | 0.990 | 0.050 | 2.060 | 1.120 |
| 1.5636 | 1.130 | 1.170 | 0.040 | 1.270 | 0.140 | Imaginary. | | Imaginary. | |
| 1.5616 | 1.270 | 1.336 | 0.066 | 1.730 | 0.460 | | | | |
| 1.5604 | 1.360 | 1.450 | 0.090 | 2.460 | 1.100 | | | | |
| 1.5576 | 1.540 | 1.750 | 0.210 | | | | | | |
| 1.5572 | 1.580 | 1.800 | 0.220 | | | | | | |
| 1.5544 to 1.5535 | 1.810 to 1.870 | 2.105 to 2.260 | 0.295 to 0.390 | | | | | | |
| 1.5520 | 1.980 | 2.460 | 0.480 | | | | | | |
| 1.5515 | 2.030 | 2.524 | 0.494 | | | | | | |

NOTE.—A part of the above values of $n$, where determined from observation by the bolometer, are liable to error in the fourth decimal place For probale errors of $\lambda$ see Table 2. "$\lambda$ observed" is either from a direct observation or from an interpolation between two closely contiguous observations.

It is evident that Briot's formula, though not exact, yet gives results much more trustworthy than the others considered, and it was employed in constructing provisional maps of the normal spectrum from the prismatic, until an apparatus was completed for determining the wave-lengths of the invisible rays by direct measurement.

We must evidently conclude from the numbers in Table 4, and from the curve in Plate XI, which embodies them, that we in reality can scarcely assign any limit to the extent of the infra-red prismatic spectrum, and that far from the curve having an asymptote parallel to the axis of X, as CAUCHY's theory requires, our curve (so far as we can follow it) rather tends to ultimately coincide with a straight line cutting the axis at a finite angle, and (if this axis pass through the point $n=1$) at a great distance from the origin.

With the danger of extra-polations presented to us in such examples as have been cited, we shall not attempt to generalize the results of our observations, further than to remark that for the prism in question, we find that the deviation tends within the limits of observation to become proportional to the wave-lengths, as the deviation diminishes, and that as far as we can see at present, there is scarcely any limit to the wave-length our prism can transmit except that fixed by its absorptive effect.

The approximate limit of the solar spectrum of the HILGER prism is at $n$ 1.5435, which according to BRIOT'S formula, corresponds nearly to $3\mu.1$, but which according to our bolometric observations corresponds to an actual wave-length of $2\mu.8$. For this same point, as will be seen by Table 4, the values by CAUCHY'S formula are impossible, and those by REDTENBACHER'S equally so.

We may add that BRIOT'S formula gives a point of inflection near $\lambda=2^{\mu}.0$. In other words, the curve which up to near the limits of our chart (Plate XI) has been convex to the axis of $x$, there becomes concave. These values for BRIOT'S formula rest, it will be remembered, on extrapolations founded on measures in the visible spectrum.

### WAVE-LENGTHS OF COLD LINES IN INFRA-RED PRISMATIC SPECTRUM.

The following values (in Table 5) from MOUTON, ABNEY, and DRAPER are the only ones I know previous to my own measures where the wave lengths of any cold lines are given with approximate accuracy. Of these it is just to distinguish those by ABNEY as possessing a degree of exactness before unknown. There are some doubts about the band $1^{\mu}.36$ to $1^{\mu}.37$ having really been observed before, but I have included this among those whose existence was known or suspected before my measures.

The values here given were obtained by me in 1882, and first published in the Comptes Rendus of the Institute of France, for September 11, 1882, in the form of charts, which were drawn from them. (The original charts have been given here already on a reduced scale in Plate XIX.) These charts were so much reduced by the first engraver that though these values are still determinable from them, it may be convenient to repeat them here in their original tabular form, with the addition of the probable errors.

*Table V.—Observed values of cold bands in infra-red by different investigators.*

| M. Mouton.* | W. de W. Abney.† | J. W. Draper.‡ | S. P. Langley.§ |
|---|---|---|---|
| $\mu$ | $\mu$ | $\mu$ $\mu$ | $\mu$ $\mu$ |
| ................ | 0.824 | 0.815 to 0.835 | 0.815 ± 0.003 |
| 0.850 | 0.851 | ................ | 0.85 ± 0.003 |
| ................ | 0.899 | 0.893 to 0.930 | 0.89 ± 0.004 |
| ................ | 0.905 | ................ | 0.91 ± 0.004 |
| ................ | { 0.941<br>{ 0.983 | 0.935 to 0.980 | { 0.94 ± 0.004<br>{ 0.98 ± 0.004 |
| 0.985 | ................ | ................ | 1.13 ± 0.007 |
| 1.230 | Possibly ABNEY'S "$\varphi$" | ................ | { 1.13 ± 0.007<br>{ 1.18 ± 0.007 |
| 1.480 | ................ | ................ | 1.27 ± 0.007 |
| ................ | Possibly ABNEY'S "$\psi$" | ................ | { 1.36 ± 0.008<br>{ 1.37 ± 0.008 |
| ................ | ................ | ................ | 1.54 ± 0.009 $\chi$ |
| ................ | ................ | ................ | 1.58 ± 0.009 $\psi$ |
| ................ | ................ | ................ | { 1.81 ± 0.010<br>{ 1.87 ± 0.010 } $\Omega$ |
| ................ | ................ | ................ | 1.98 ± 0.010 $\omega_1$ |
| ................ | ................ | ................ | 2.03 ± 0.010 $\omega_2$ |

* M. MOUTON, Comptes Rendus, tome lxxxix, p. 298; tome lxxxviii, p. 1190.
† W. de W. ABNEY, Phil. Trans., 1880, p. 653.
‡ J. W. DRAPER, Proc. Am. Acad., 1881, p. 223.
§ S. P. Langley, Comptes Rendus, Sept. 11, 1882; Am. Journal of Science, March, 1883, &c.

### LINES KNOWN TO PREVIOUS INVESTIGATORS.

(0.815.) Near the utmost limit of visibility. Appears to coincide with Captain ABNEY'S Z, and DRAPER'S $\alpha$.

(0.85.) Apparently agrees with ABNEY'S 8540.

(0.89.) An inconspicuous line. ABNEY has a heavy line near here. Possibly corresponds to DRAPER'S $\beta$.

(0.91.) Inconspicuous; possibly a part of DRAPER'S $\beta$ (0.89 and 0.91 from part of a group called $\pi$ by ABNEY).

(0.94 to 0.98.) Very heavy band; marks the extreme limit of DRAPER'S investigations, according to his own statement; possibly identifiable with a gap in LAMANSKY'S curve, and corresponding to the group called "$\rho \varsigma \tau$" by ABNEY. (Allegheny observations make it probably telluric.)

(1.13 to 1.18.) Still colder than preceding; possibly identifiably with a gap on LAMANSKY'S curve, and with ABNEY'S "$\varphi$". (Allegheny observations make it probably of telluric origin.)

(1.27.) Inconspicuous line.

(1.36 to 1.46.) Very remarkable band. Almost absolutely cold and black. So broad and diffuse that it is difficult to mark its limits, but coldest part seems to have a wave-length of 1.36 to 1.37. (Allegheny observations make it probably of telluric origin.) Possibly $\psi$ of ABNEY'S chart, and identifiable with the last gap of LAMANSKY'S curve. It seems to be the "*ultima Thule*" of previous investigations.

NEWLY-DISCOVERED LINES AND COLD BANDS..

(1.52 and 1.59.) Inconspicuous lines.

(1.81 to 1.87.) Great Cold Band, first discovered on Mount Whitney. Probably of telluric origin. It is not the furthest line, but is here called $\Omega$ on account of its being the last *conspicuous* break in the energy curve.

'(1.98 and 2.04.) Small but definite lines. The last discovered by the bolometer. But the observable solar spectrum certainly extends to a wave-length of over $2^{\mu}.70$.

DISTRIBUTION OF ENERGY IN THE NORMAL SPECTRUM.

The curve $d = \varphi\lambda$ given in Fig. 3 enables us to mark off a wave-length scale upon the map of the prismatic spectrum, without any extra-polation, between our present points of observation, a deviation of 50° 58′ (corresponding to $\lambda = 0\mu.344$), and a deviation of 44° 25′ (corresponding to $\lambda = 2\mu.356$), and also to construct a map in which the wave-length scale is an ordinary scale of equal parts, but in which the degrees of deviation, if represented, would be unequally spaced. Such a chart of the *normal spectrum* has, as we have already remarked, the advantage of being entirely independent of any particular prism or grating, and consequently of being directly comparable with all other maps of the same kind.

If, besides making a map of the normal spectrum, we wish to construct a curve representing the corresponding distribution of energy, a further consideration of the relations existing between the two charts is necessary. The law of dispersion of the prism causes the distribution of energy in its spectrum to be quite different from what would have been observed with a diffraction grating.* Disregarding the absorbing action of the apparatus, the amount of heat between two definite wave-lengths, as between the A and B lines, should be the same in both spectra, provided the total quantity of heat is the same in both. The area between any two ordinates of the curve may be considered to represent the amount of heat in the part of the spectrum included between them, and the total area of the curve represents the total amount of heat. If, then, we suppose the area of the normal curve required, to be the same as that of the prismatic one, the condition to be fulfilled by the former curve is that the area included between the ordinates at any two wave-lengths shall be equal to that included between the same wave-lengths in the latter, and from this condition we can deduce a rule for effecting the required transformation.†

Lay off upon a line, AB (Fig. 3), any convenient distance, and divide it into equal spaces to

* J. W. DRAPER, Phil. Mag., vol. xliv, p. 104, 1872.

† See J. Müller, Pogg. Annalen, vol. cv; Lundquist, Pogg. Annalen, vol. clv, p. 146; Mouton, Comptes Rendus, vol. lxxxix, p. 298.

represent the normal wave-length scale, and upon a line, CD, at right angles to the first, lay off the same distance and divide it into the same number of parts, spaced according to the law of dispersion of the prism, as in the wave-length scale marked on the bottom of the prismatic chart, Plate I. Erect ordinates at the points of division, and mark them with the proper wave-lengths, beginning on both lines at the ends which lie nearest to each other, as in the figure, where five ordinates are shown; through the intersection of corresponding ordinates draw the curve EF and upon CD draw the curve of distribution of energy in the prismatic spectrum.

Let $a$, Fig. 4, be a very small wave-length interval on the prismatic scale; $c$, the same interval on the normal scale, and $b$ and $d$ the average heights of the energy curves over the two intervals, respectively; the shaded part of the figure representing, therefore, the portion of the total area included between these limits, $ef$ is a portion of the curve EF, Fig. 3. Then, according to the condition of transformation,

$$cd = ab$$

whence

$$b : d :: c : a$$

From geometrical considerations,

$$c : a :: 1 : \tan \varphi$$

where $\varphi$ is the angle which the cord EF, joining the intersections of the two pairs of ordinates makes with AB; consequently

$$b : d :: 1 : \tan \varphi$$

from which

$$d = b \tan \varphi$$

Now, when $a$ and $c$ are indefinitely small, $b$ and $d$ are the ordinates of the prismatic and normal energy curves, respectively, at a given wave length, and $\varphi$ is the angle formed by the tangent to EF at their point of intersection. Hence, to find the height of the normal curve at a given wave-length, the corresponding ordinate of the prismatic curve must be multiplied by $\tan \varphi$.

Such a construction was applied to the prismatic energy curve of the HILGER prism.

The true normal energy curve with all its inflections, maxima and minima, is easily drawn after this (dotted) bounding curve of normal energy is plotted, for the parts of the ordinate of the latter below and above its intersection with the former irregular curve bear the same proportion to each other as in the prismatic spectrum, and we thus finally attain the object of the preceding labor.

If, now, it is desirable to map the distribution of the energy on any other scale, such as that on which the abscissæ are proportional to the times of vibration, this can be done with facility. Thus, in the supposed instance, we have only to find $\frac{1}{\lambda}$ corresponding to each wave-length in order to get the abscissæ, and (observing that since $x$ now $= \frac{1}{\lambda}, \frac{dx}{d\lambda} = -\frac{1}{\lambda^2}$) to use the multiplying factor $\frac{1}{\lambda^2}$ to obtain the length of the new abscissæ from the old in each instance. If the length of the new energy curves between the limiting perpendiculars (which now represent the reciprocals of the wave-length), is to be the same as in the old, we must introduce a constant multiplier, $n$, writing the equation of the interpolating curve $x = \frac{n}{\lambda}$, so that the multiplying factor becomes $-\frac{n}{\lambda^2}$. Thus if the limiting ordinates of the wave-length energy curve are $\lambda_a$, $\lambda_b$, and we are to have the condition $\left(\frac{1}{\lambda_a} - \frac{1}{\lambda_b}\right) n = \lambda_b - \lambda_a$, $n = \lambda_a \times \lambda_b$, &c.

If the mean ordinate of any small area of the normal energy curve between any given limits, $\lambda_a$, $\lambda_c$, is denoted by $y_1$, and that of the corresponding area of the new curve by $y$, since the areas

Fig. 3.

ILLUSTRATING PRINCIPLE OF TRANSFORMATION FROM THE PRISMATIC TO THE NORMAL SPECTRUM.

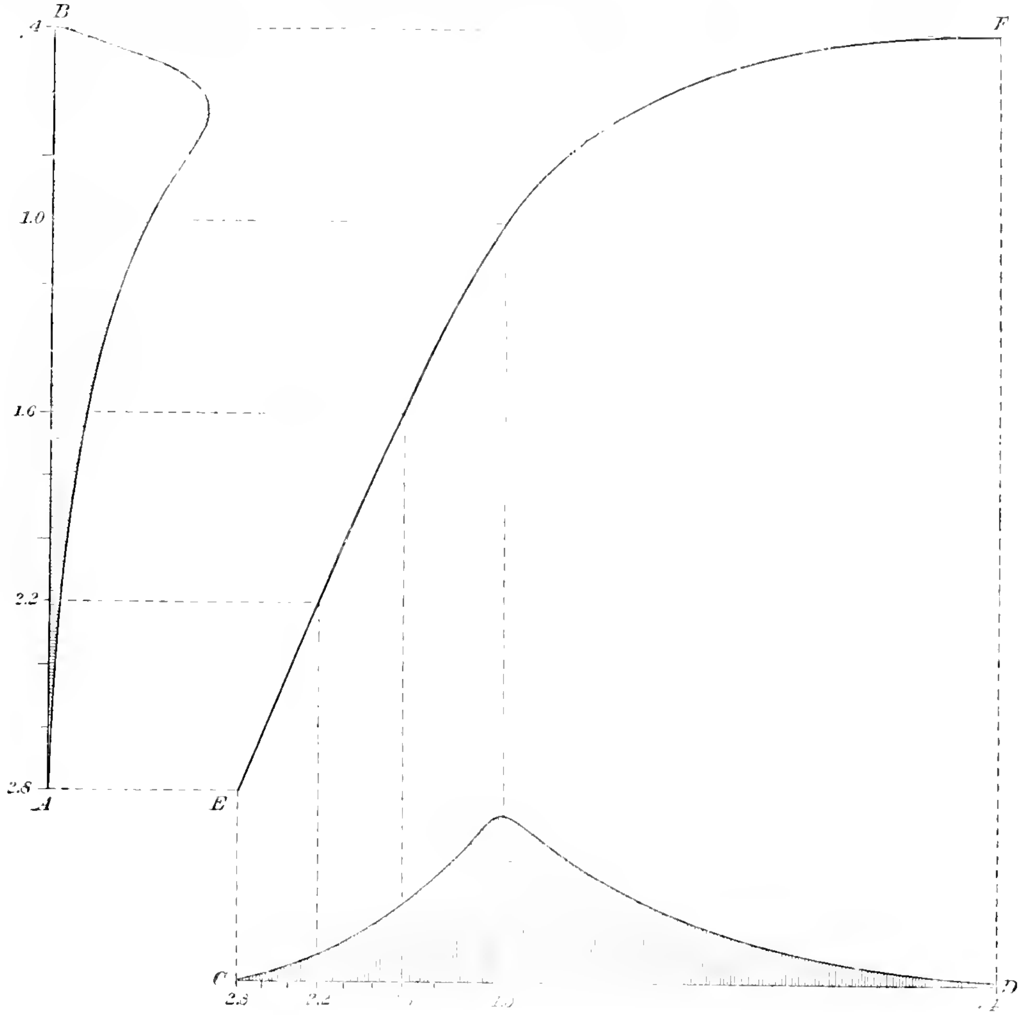
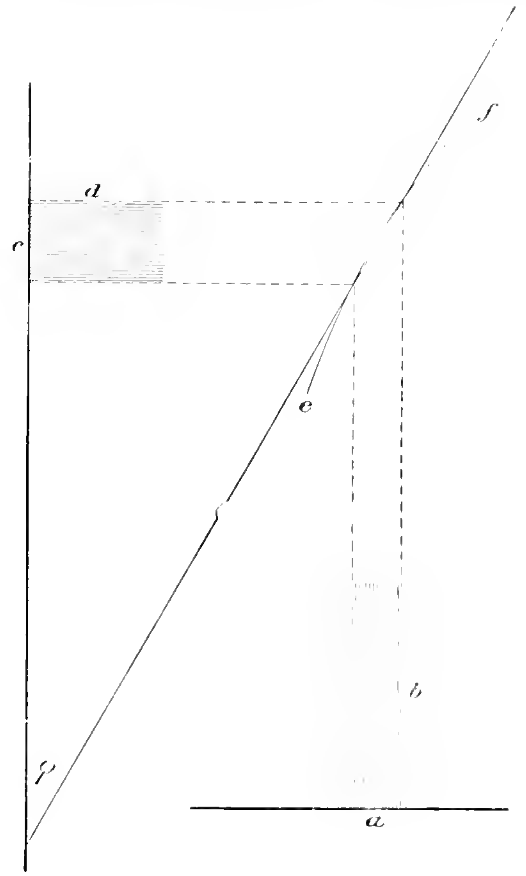



Fig. 4.

ILLUSTRATING PRINCIPLE OF TRANSFORMATION FROM THE PRISMATIC TO THE NORMAL SPECTRUM.



are to be the same, we have $n\left(\frac{1}{\lambda_{n}}-\frac{1}{\lambda_{r}}\right)y=(\lambda_{n}-\lambda_{r})\;y_1$, whence $y=\frac{\lambda_{n}\,\lambda_{r}}{n}\times y_1$, which at the limit becomes $y=\frac{\lambda^2}{n}y_1$. Hence to obtain the new ordinates the old ones must be multiplied by the reciprocals of the factors for abscissæ, or by $\frac{\lambda^2}{n}$.

The curve EF, Fig. 3, if represented by a formula, would give rise to an expression of the form $d=(\varphi)\lambda$, the abscissæ measured along AB being proportional to the wave-lengths, and the ordinates parallel to CD to the deviations. Since $\tan\varphi=\frac{dd}{d\lambda}=\frac{dn.\,dd}{d\lambda.\,dn}$, the factors for multiplying the prismatic ordinates may be computed, provided the curve EF can be exactly expressed by a formula, and for the preliminary reduction this was done, the values of $\frac{dn}{d\lambda}$ being computed from BRIOT's formula, and $\frac{dd}{dn}$ from the relation $n=\frac{\sin\frac{1}{2}(a+d)}{\sin\frac{1}{2}a}$. When, however, it was shown by the measurements of obscure rays that BRIOT's formula, obtained by observations in the visible spectrum, does not exactly express the law of dispersion, the table of factors thus prepared was of course abandoned, and the graphical method described above was substituted.

I have drawn in this way (on a smaller scale than that of the normal or prismatic curves and following the smooth curve in the former as my original) four different schemes for the distribution of the energy. Curve B, Plate XXI, represents the distribution of solar energy after absorption by our atmosphere on the scale of wave-frequency (general equation of interpolating curve $x=\frac{1}{\lambda}$, proposed by Mr. STONEY). Curve C, Plate XXI, represents the distribution according to a proposal ($x=\log\lambda$) of Lord RAYLEIGH.

Curve D ($y$=C) Plate XXI, is quite different from any of the preceding. It gives the distribution on a scale I have never seen proposed, but which I have found useful. In this the bounding curve is a *straight line* parallel to the axis of X. This construction is not well suited to exhibit the cold bands, but if we consider only the general distribution of the energy, we shall find that curve D is not merely suggestive as illustrating what has already been remarked here as to the conventional character of the methods of showing this distribution, but that it has more practical uses, for in this last construction it is easily seen that the sums of the energies between any two wave lengths whatever are directly proportional to the distance between their ordinates, measured on the axis of X. If, then, we desire (for instance) to know what relation the invisible bears to the visible heat, or to inquire about what point in the spectrum the energy is equally distributed, these and similar problems are solved through curve D by simple inspection.

I have not been able yet to repeat the preceding determinations upon the lower part of the spectrum as often as I could wish. They are susceptible of improved accuracy by still longer experiment, but I think that within the limits of error indicated they may already be useful. I should add that throughout this investigation I have received constant and valuable aid from Mr. J. E. KEELER, not only in the graphical constructions, but in the experiments and in the computations, through all the details of which his aid has been more that of a coadjutor than an assistant.

ALLEGHENY OBSERVATORY, *Allegheny, Pa., October*, 1883.

NOTE.—Since the above was in type I have seen the interesting article by M. H. BECQUEREL in the Annales de Chimie for September, 1883.

The wave-lengths assigned by M. BECQUEREL to the band at the limit of his researches, at 1460 to 1480, appear to me too great, for this limit corresponds to the band whose wave-length is given at $1\mu.36$ to $1\mu.37$ on my chart published in the Comptes Rendus of the previous year (September 11, 1882), and on a larger scale in the American Journal of Science for March, 1883, and in the Annales de Chimie for August of this year. I regret that M. BECQUEREL has not read the article in the Comptes Rendus. Had he done so he would have seen that the wave lengths there given were not conjectural, but directly determined by the only practical method—from the use of a grating. They were the result, in fact, of the measurements I have just described, and were specially intended to give information about the unknown region extending beyond the limit of M. BECQUEREL'S researches, such as the great newly discovered band $\Omega$, for instance, which stretches from wave-lengths $1\mu.80$ to $1\mu.90$, while M. BECQUEREL'S furthest band, as I have said, is at $1\mu.48$, according to him, but really nearly at $1\mu.38$. The present memoir will show what degree of reliance may be placed on these measurements.

It is understood that a photographic map of the spectrum to $1\mu.6$, and therefore covering the ground of M. BECQUEREL'S paper, but not extending as far as my $\Omega$, will shortly be published from the joint labors of Professor ROWLAND and Captain ABNEY, and as their results will probably be accepted on all hands as more exact than the preliminary explorations in which M. BECQUEREL and myself have been engaged, we may await its appearance for the determination of a part at least of the points in question.

I would call attention to the fact that M. BECQUEREL has stated that the furthest band known to him in September, 1883 (except from my own researches), had a wave-length of not over $1\mu.50$, according to his own estimate.

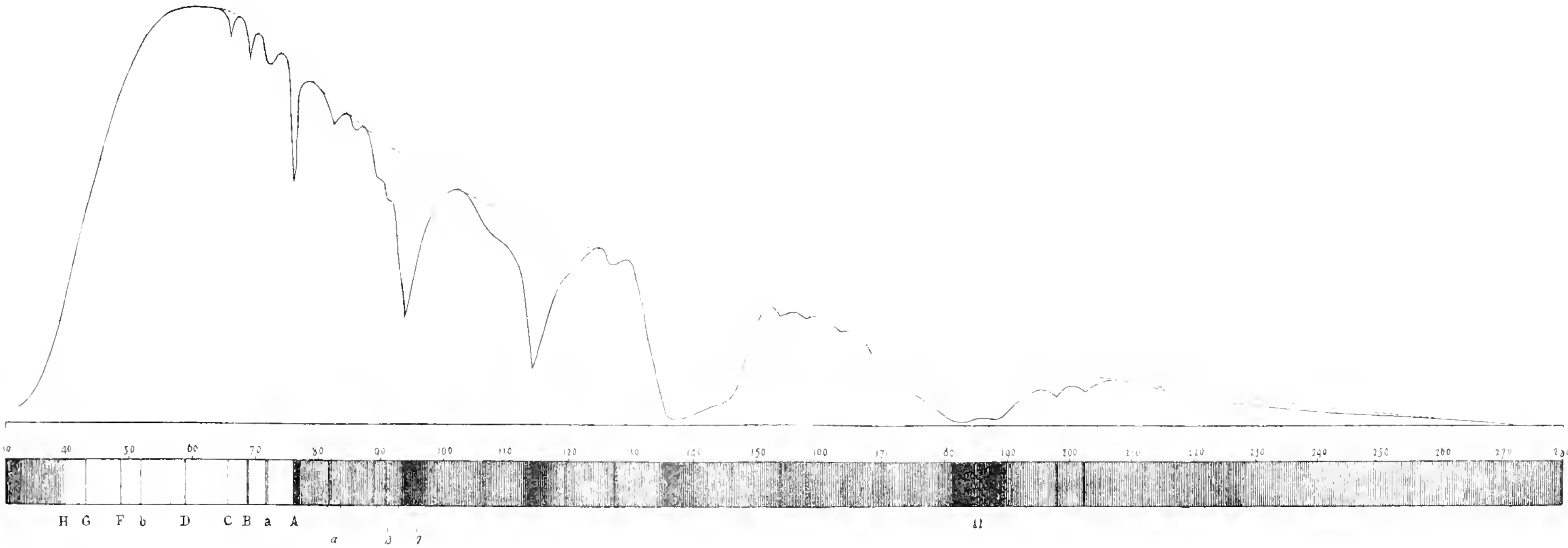



PLATE XII

NORMAL SPECTRUM

(ENERGY CURVE)

S. MIS. 110, 1, 48.

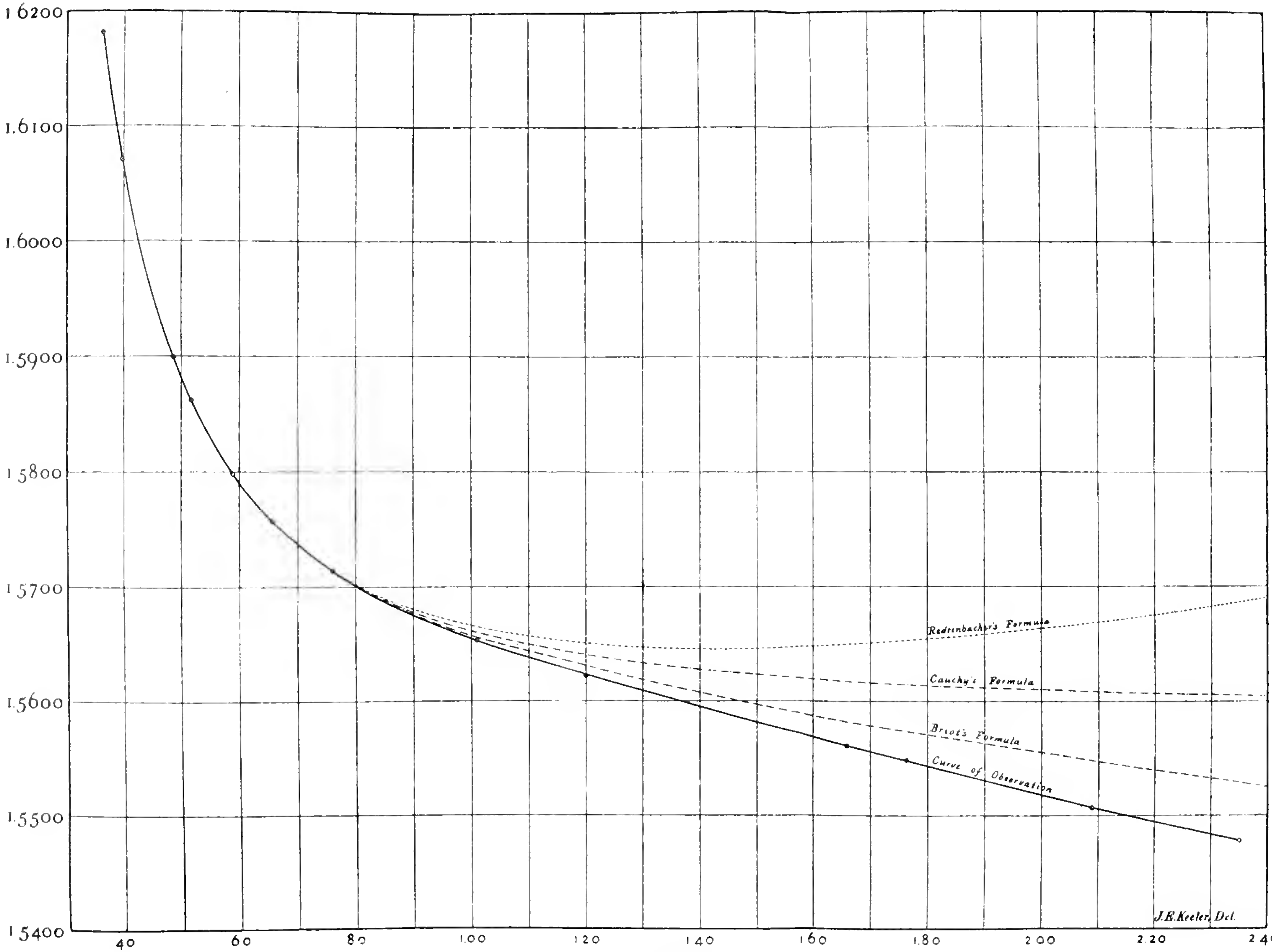



PLATE XIX.

CURVE $n = f(\lambda)$ FOR THE HILGER PRISM.

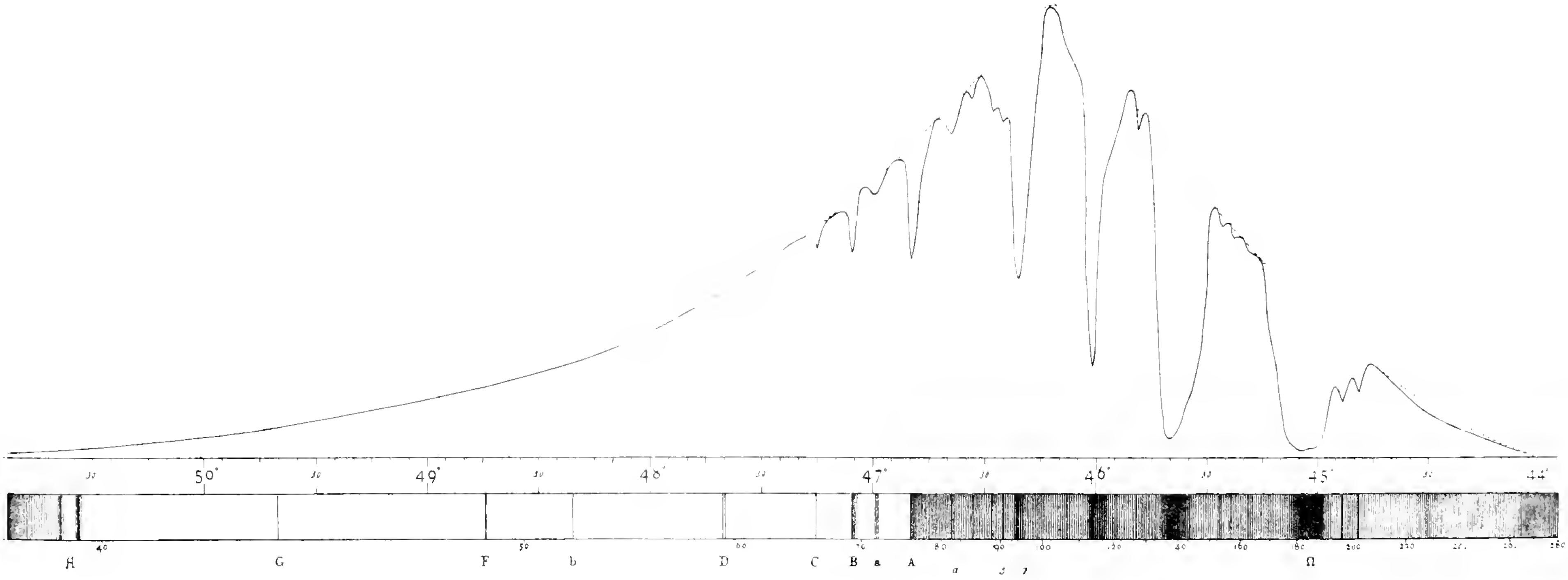



PLATE XI
PRISMATIC SPECTRUM.
(ENERGY CURVE)

S. MIS. 110, 1, 48.

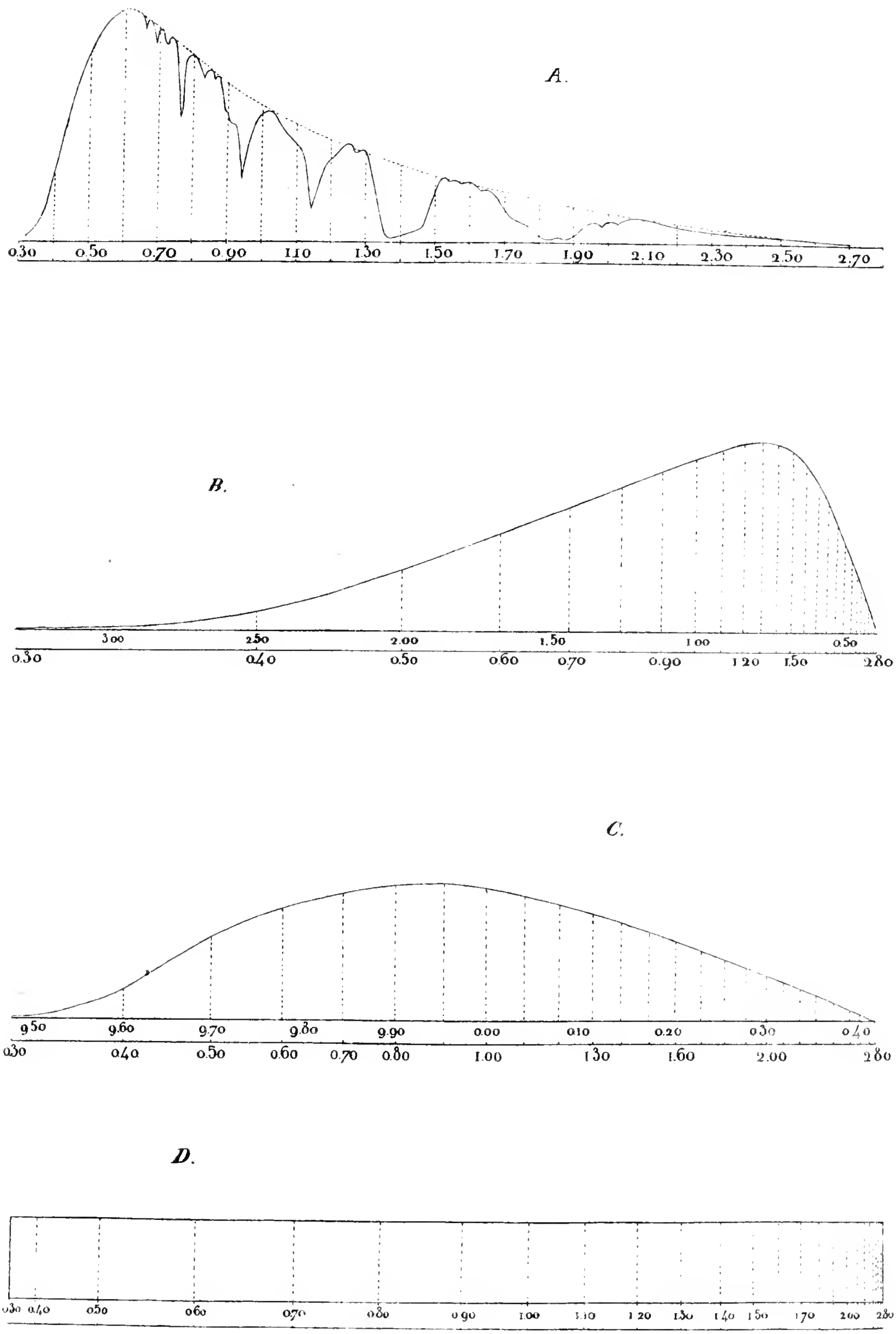



PLATE XXI.

SCHEME FOR DISTRIBUTION OF ENERGY.

A. B. Schanz, Del.

S. MIS. 110, 1, 48.

NATIONAL ACADEMY OF SCIENCES.

THIRD MEMOIR.

# ON THE SUBSIDENCE OF PARTICLES IN LIQUIDS.

BY

PROF. WM. H. BREWER.

# ON THE SUBSIDENCE OF PARTICLES IN LIQUIDS.

*READ AT NEW HAVEN MEETING, NOVEMBER 15, 1883.*

While connected with the State Geological Survey of California, 1860–'61, my attention was turned to the relations of saline and alkaline waters to the precipitation of suspended matter. There were abundant means of observation in the field, but no laboratory experiments were made. Soon after the republication by the Ray Society, in 1866, of ROBERT BROWN'S observations on the movements of minute solid particles in liquids, I began a series of experiments on these "Brownian movements" in their relations to sedimentation, but unfortunately I have now no systematic record of the experiments made previous to February, 1875, since which time the experiments have been much extended and systematic records have been kept of many of them. In 1877 I published some of the observations in their relations to agriculture (*11th Ann. Rep. Com. State Board of Agr., p.* 73–83), and in 1880 further observations in their sanitary relations—on the action of muddy water on sewage—*Public Health Papers and Reports, vi*, 334), and in 1881, in a lecture (not published further than in ordinary newspaper reports), I further discussed the matter in connection with the problem of the jetties at the mouth of the Mississippi River.

Since 1877 the experiments have been much expanded and have gone on along several lines of investigation. They extend to a considerable number of clays, soils and other suspended matter, and the records and notes have now become somewhat voluminous. Inasmuch as prolonged time is an element in some of the experiments, and as this meeting enables me to exhibit some of the specimens to the academy, I take the occasion to report on some of the observations made and inferences deduced from these long-continued observations and still unfinished experiments.

It is a matter of common observation that fine clays and muds may remain long suspended in fresh water, but it is commonly believed that if the water be left at rest complete sedimentation takes place within a few weeks or months at most, leaving the water clear: that salts of many kinds hasten the settling, and that also acids hasten it. Some writers have stated that dilute alkalies retard it and may prolong it even indefinitely, and numerous observers have noticed that during the subsidence of clays in perfectly still fresh water they are often disposed in layers or strata of different degrees of density, giving to the liquid different degrees of opacity.

In this paper I do not purpose to review the history of our knowledge of this subject, nor to discuss the published observations or experiments of others; that is left for a future paper. It will better serve my present purpose to discuss my own experiments (with the exhibition of a few of my specimens), with only so much allusion to the labors of others who have wrought in the same field as is necessary for an understanding of my own work.

If clays containing some fine sand, as most clays do, are thoroughly mixed with pure fresh water and then allowed to stand in perfect quiet in a suitable vessel, a portion, including all the coarser particles, soon falls to the bottom, but a considerable portion remains longer suspended. The water may become nearly clear in a day or two, or finer material sufficient to render the liquid opaque in vessels three or more inches in diameter may remain suspended for weeks.

In these latter cases the liquid usually becomes disposed in strata; that is, the suspended matter will not fade gradually in density from the bottom upwards through regularly diminishing opacity to the top, but will rather be disposed in successive layers, the limits of each more or less well defined.

Different specimens of clays and soils behave quite unlike in this respect, so far as the details go. A few do not show these strata at all, the suspended matter fading gradually and regularly in density, and such clays usually settle comparatively rapidly. Others show the character but feebly; there may be but two such layers, or, if more, the limits of each may be very illy defined. Some show as many as six or eight, or even more, in which cases they are of unequal thickness, and sometimes the limits of each are surprisingly distinct.

If left perfectly quiet, the heavier go down first, and at last all are down but one, and the liquid is then uniformly opalescent from bottom to top. This may be after a week or two or it may be only after many months. With further quiet this opalescense gradually fades evenly from top to bottom, the rapidity of this clearing of the liquid being modified by several external conditions.

The fading of this opalescense by subsidence goes on slower in the light than in the dark, but how nearly this is related to changes of temperature I have not been able to determine, as any place at my command from which light is excluded is subject to less fluctuation of temperature than where it is abundant. The nearest approach to similar conditions other than light has been in an instrument closet in my lecture-room, built against a firm interior brick wall, the upper part of the case being closed by glass and the lower part by wooden doors. When similar specimens have been exposed in these two cases at the same time, the fading of the opalescense by subsidence has been more rapid in the dark case than in the adjacent light one.

If the experiment goes on in a place of perfect quiet and in the dark, and where the daily changes of temperature are slight and very gradual, then the opalescense gradually fades with time; but how long before it will entirely fade away and the liquid become clear by the subsidence of the particles (if indeed it ever will) I cannot say, but certainly not in six years, some of my samples having now stood longer than that time.

If, however, the experiment is conducted in an ordinary lighted room, with the fluctuations of temperature incident to habitation or use, then after a time the opalescense ceases to fade; it may remain stationary as to intensity, or it may increase and diminish with the seasons and other fluctuating conditions. How much such fluctuation in opalescense is owing to convection currents produced by the fluctuations of temperature, and how much to other causes, I have found no means to determine.

The color of this ultimate uniform opalescense is usually milky, but with some ferruginous clays it is red, brown, or of different shades of amber; with certain other clays it has various shades of pale green and yellowish green. This is strikingly the case with certain clays from the bad lands of Wyoming, the shades of color of which remind one of the tints of some of the Swiss lakes as seen from the alpine heights above them, which tints and colors I suspect may be due to a similar cause.

Temperatures above that found naturally in the free air and also below the freezing point are each accompanied with their special phenomena.

The boiling of clays in a great excess of water tends to reduce them to the finest division, and this is the method employed by Professor Hilgard in his elaborate and most instructive investigations on the physical conditions and composition of soils. Some clays go to pieces easily on boiling, while others, according to this authority, have to be boiled for many hours, it may be for days (and with precautions to prevent flocculation), before the process is complete. I find that many, if not most, clays behave very differently in hot water from what they do in cold, and different clays differ in behavior in hot water.

Some clays which go to pieces easily in cold water, and which settle slowly if the water remains cold, settle rapidly if the water be raised to near the boiling-point. Some such clays which have been experimented upon, which will remain suspended in large quantity for many days if kept cold or at ordinary temperatures, if the water be gradually heated, when a certain temperature is reached the clay suddenly flocculates or curdles, and settles in a very bulky, mobile mass long before the water begins to boil, and during the boiling there is this constant tendency to flocculate, the suspended matter behaving much as it does in the presence of certain chemicals, to be noted later. If the heat be removed and the liquid allowed to cool slowly, the phenomena are reversed. While hot, much of the suspended matter curdles and falls in a very bulky, mobile mass, which if shaken soon falls back again until the water reaches a certain reduction of temperature, when, if the material be shaken, it will require several days for any part to become so nearly clear as the upper part would be in a few minutes if hot. I think it probable that some of the colors described in the hot springs of the Yellowstone region may be related to the behavior of clays in hot water.

Again, freezing affects the suspension. If water holding suspended particles be frozen solid and then be thawed again, it is rendered much clearer by the operation. The mud becomes largely disposed along certain lines of crystallization in the ice, and if this be slowly thawed in the quiet, it falls and does not rise again. In one set of my experiments the water in which a red ferruginous clay was suspended froze partially solid, a portion of the liquid being entirely surrounded by ice. In the liquid the suspended matter was ultramicroscopic, but in the ice the red material was concentrated in visible particles along certain lines, curiously disposed relative to the crystallization and to the inclosed air-bubbles. Stereoscopic photographs show the arrangement in the mass, but drawings are very unsatisfactory.

In one such case, when the liquid, much cleared by the freezing, was placed near a window where the sun struck it a little while each day, it soon became turbid again, possibly by convection currents caused by the sun's heat; but similar specimens melted in the dark and kept in the dark remained as clear as the freezing had made them. Changes in ink by freezing are familiar to all, and probably due to the same cause.

Some clays, if thoroughly dried, and then moistened again, and then frozen and thawed in a wet state, behave very differently in water before and after such freezing.

The fallen sediment from different clays varies greatly in hardness and tenacity, the differences not following the relative proportions of sand in the original material under experiment. With some samples, even of very fine clay, the suspended portion may be very large and the dense turbidity remain a long time, and yet the sediment which does fall be very firm in a day or two, while others may fall speedily into a bulky mass as mobile as the water itself, which shrinks and is compacted very slowly indeed in the water. Some sediments, when they have stood a few days or weeks in the liquid from which they have subsided, are so firm that it requires much and long agitation to again diffuse them through the water; others, after several years' standing, may be entirely diffused by a few seconds' agitation.

It is obvious that each and all of these various facts have their geological significance, and phenomena immediately suggest themselves where they certainly or possibly play a part.

Thus far I have only described the behavior of clays and suspended matter to fresh water, and in many of my experiments distilled water has been used.

In solutions of various kinds, the phenomena are very different, and experiments have been conducted with various acids, alkalies, salts, extracts, and neutral organic substances.

Some of the more general facts are well known and widely applied. The use of certain salts to clear turbid waters, and of organic substances to correct unwholesome waters, are of wide application, and have been known from antiquity. (See *Exodus*, xv, 23.) Alum is used in many countries where the drinking water is turbid. I have often heard of its use in the Mississippi Basin; also in South America and Europe: and Mr. Arnold Hague tells me that he found it in universal use in the Loess country of Northern China, where it has been used for this purpose for ages.

The rapidity of sedimentation in the presence of certain salts and acids, as contrasted with the behavior of the same material in fresh water, is indeed striking. I exhibit one specimen to the academy especially notable in this character, and which has been used to illustrate the general fact to my classes. The original is a very hard, greenish, eocene clay, from the Niobrara region, which when ground up in pure water settles very slowly. For class-room illustration a quantity which has stood some days, for the coarser parts to settle, is decanted and divided into two equal portions at the beginning of the lecture. To one a solution of common salt is added, to the other an equal volume of distilled water, that the opacity of the two be equal at the start. Before the close of the lecture the upper part of the one will be clear, or nearly so, the other apparently unchanged. The specimen I exhibit to the academy was thus used; it is the portion in pure water, and after over thirty months of standing at rest is not yet so clear as its companion portion in salt water became (during the lecture) in less than thirty minutes.

When a solution of common salt (or of sea-water) is added to muddy water, the suspended clay curdles or flocculates and immediately begins to fall, and in a comparatively short time the liquid becomes clear. If the clear part be decanted, an equal volume of distilled water be added, the sediment again diffused through the liquid by agitation, and the process be repeated, the saltness of the solution being reduced at each dilution, the behavior of the same identical clay in the same quantities of solution of different degrees of strength may be observed, if time enough be given to the observations. We may say, in a general way, that the stronger the solution the quicker the precipitation; but the rapidity is not directly as the quantity of salt dissolved. Reducing the saltness one-half does not necessarily double the time required for the solids to settle. With some clays the precipitation in a solution as strong as sea-water, or even half as strong, is as much in thirty minutes as in as many days, or even months, if the water be pure; and if the amount of salt be increased, the rapidity of sedimentation is not correspondingly increased. On dilution by decantation as described, the precipitation becomes slower and slower. When the liquid contains but one-tenth or one-twentieth the amount of salt found in sea-water, the precipitation becomes very slow, but in a few weeks or months the liquid becomes as clear and pellucid as the clearest natural waters. As the dilution goes on and the water contains less and less salt, its capacity becomes greater for holding the clay in suspension, both as to the quantity that may be suspended and the length of time it will hold it. The identical mud previously thrown down rapidly in salt or brackish water, when the water becomes fresh is again picked up, on agitation, and is again held in suspension. This may be repeated indefinitely. Each time salt is added the settling is hastened, and with each freshening the mud is again suspended longer.

I have tested this with numerous muddy waters produced artificially, and also on the actual river water taken from the Mississippi River below New Orleans, and from the Missouri River, 2,800 miles above, and on other natural muddy waters. Different specimens behave somewhat differently as to degree and in details, but the essential facts are the same for all the samples I have experimented upon. I believe that the phenomena have an importance not heretofore given to them either by geologists, physical geographers, or engineers.

The formation of bars at the mouths and in the channels of rivers, and the distribution of silt on the floor of the ocean and of lakes, have usually been discussed and considered from the hydraulic side only, the direction and velocity of the current have been considered as the only factors of any considerable importance, but I believe that the chemical composition of the water plays an essential and controlling part in the effects produced.

The phenomena attending the formation of bars at the mouths of rivers which empty into fresh-water lakes, and the depositions which take place in the channels of rivers where the water remains fresh all the year through, are very unlike those attending the formation of bars in salt water at the mouths of muddy rivers, or the silting of the channel just within the mouths of such rivers, where the water becomes brackish before reaching the sea.

In fresh-water rivers and at their mouths in fresh-water lakes, the more obvious changes in the bars take place only at the time of floods, and the movement and deposition of the material are in strict accordance with hydraulic laws. The "hydraulic value" of particles of known size and specific gravity has been experimentally determined with great care and accuracy. The deposition of the finer material takes place in the still waters, and at low water and is comparatively slight in quantity in any one year.

But when a muddy river enters salt water, chemical laws interfere with the purely mechanical ones, another set of phenomena are introduced, and the growth of the bar is different. Then the rate of deposition is affected by the salt more than by the current, and velocities which would be much more than sufficient to carry the finer suspended matter indefinitely if the water were fresh, entirely fail where the water is brackish or salt. Practically it is the degree of saltness which controls the deposition.

In the phenomena exhibited at the mouth of the Mississippi River we see these principles manifested on a stupendous scale.

At time of flood, when the whole water is fresh to the bottom of the river and to its very mouth, then no considerable deposition occurs in the channel within the mouth; the mud is carried outside and largely deposited on the outer slope of the bar, notwithstanding the agitation by the waves at that point. At the same time the channel within the mouth is scoured out and the inside of the bar is more or less abraded, or, as various engineers have expressed it, the bar is "pushed out into the Gulf" by each high water.

At low water the salt water from the Gulf runs back into the river, first as a stratum on the bottom, with a layer of the lighter fresh and muddy water over it; then later the river becomes brackish to its surface, this condition extending to the head of the passes, or further, according to the season and the amount of water. Then a large deposition always takes place on the inner slope of the bar, and in the channel within the mouth, and up to the head of the passes. I was told on the spot that this takes place every year, and that since the jetties have been built, the required depth for navigation is only then maintained between the jetties by some dredging. As the channel is closely watched and soundings made every week from the head of the passes to the Gulf, the phenomena are easily studied. And let it be borne in mind that the time when this deposit takes place within the mouth is when the proportion of mud to water is at the least, and is very much less than at high water.

When the floods of the next year come, and the waters again freshen to the bottom of the river, this deposit is picked up again by this fresh water and is carried out to the salt water, as already described. It is precisely analogous to the picking up of the material in the experimental flasks by successive freshenings. This picking up from within the river and the inner slope of the bar is by water already much heavier loaded with clay than was that from which the low-water deposition took place. Abrasion within the channel often takes place rapidly where some change of current occurs, and deep places are locally excavated to such depths that the jetties have to be protected from undermining by temporary or permanent wing-dams. The high water of the year of my visit had excavated one place to the depth of 120 feet where the water had been very shoal before the building of the jetties. A short wing-dam at the time of my visit was directing the low-water deposit into this hole, and its depth had already been reduced 40 feet.

Some of the specimens exhibited to the Academy are of mud dredged from the inner slope of the bar just within the jetties, when the turbid fresh water formed a layer 14 feet deep over the clearer salt water then on the bottom of the river channel. The material is a very unctions, tenacious clay, which becomes very tough on drying. It is as smooth as soap in the hands, but gritty with very fine sand between the teeth. The microscope shows the sand to be very minute and the finer grains very active with "Brownian movements." When agitated in fresh water a large quantity of this mud is suspended, and the liquid remains opaquely muddy for a comparatively long time, but it flocculates and settles quickly when mixed with sea-water. I have made many experiments with the several muds obtained at and near the jetties, and with river water obtained above the passes, where the water was entirely fresh, and all show essentially the same phenomena when in waters of the same freshness.

My belief is that the deposition in the channel within the mouth at low water is directly and chiefly due to chemical causes; that the scouring out at time of high water is also due to chemical causes, the velocity of the current being secondary; that a given volume of salt water, having a given velocity, will not suspend and transport an amount of clay which the same volume of fresh water, having the same velocity, would suspend and transport indefiintely; that fresh water with a given velocity will pick up from the bottom and scour out deposits which salt water of the same velocity will not, notwithstanding its greater specific gravity.

This is not only in accordance with my experiments, but it seems to me to be abundantly illustrated in the delta phenomena of the Mississippi. The local abrasions between the jetties at floods show what has occurred at successive steps all the way to the head of the delta. When the Gulf extended much farther inland, then the water was shallow both inside and outside the mouth, as it is now, but as the delta grew and the bar was "pushed out into the Gulf" by successive floods, the deep river channel followed it up from behind, the mud being picked up and carried out as the water freshened, just as it now is done between the jetties. From above New Orleans to near the head of the passes, so far as the water continues fresh at all times of the year, the channel is deep, usually more than 70 and often 100 or 120 feet deep; but all this distance the water must have been shallow when the mouth of the river was at the successive points. The shoaling of the river from where the water becomes salt, the upward slope from the head of the passes to the crest of the bar, up which slope the river must run at flood and down which the heavier salt water runs when not crowded out by floods, the deposition on the outer slope of the bar at high water and on the inner slope at low water, the deposit within the mouths when enough salt water gains admission there, and the scouring out of this again as the river freshens are all in strict accordance with this theory. My experiments explain phenomena the causes of which have heretofore been so much in dispute between the engineers who have discussed the improvement of the mouth for navigation.

Some of these phenomena were observed in connection with this very question so long ago as 1838 by W. H. Sidell, who experimented upon the action of acids, various salts, sea-water, &c.,

and concluded "that the earthy matter is deposited more suddenly than would be the case if it depended on the check of velocity alone" (*Report on the Hydraulics and Physics of the Mississippi*, Appendix, p. 500). It is very remarkable that these experiments and observations attracted no more attention during the later discussions of the problem.

The same principles explain the distribution on the floor of the ocean of the finer materials brought from the land. Notwithstanding the depth and extent of the oceanic currents, all the solids materials brought to the sea are deposited near the land. All the recent observations show that but little is carried far from shore; the profound depths of mid-ocean contain but little or none of it, and we are all familiar with the clearness and intense blue of the waters there.

My experiments have extended to a considerable variety of salts, but more especially to the chlorides, sulphates, and nitrates, to mixtures of these, and to organic substances, both colloids and crystalloids, to carbhydrates and albuminoids, extracts of woods, herbs, and of peat, and in a large number of these, clearing was more rapid than in pure water. The effect of certain neutral colloid organic substances, like the gums, is to favor suspension, as is well known.

The action of some of the salts is obviously aided in certain cases by the formation of permanent chemical compounds. This is notably the case in the reaction of alum in certain solutions containing chlorid of calcium.

The sparkling clearness of the natural waters of limestone regions is doubtless correlated with the solution of carbonate of lime, and the clearness of certain saline and alkaline waters has often been remarked. So-called "alkaline" waters in the Far West are often discolored, particularly with organic matter, but I have never seen them turbid with clay.*

Any considerable quantity of suspended carbonate of lime in water also affects the deposition of the clayey sediment, and calcareous delta deposits have special characters of their own. From what I can learn, some of the phenomena of the Nile delta, the material of which is described as a calcareous clay, are quite unlike those observed at the Mississippi delta, but my information is too meager to venture more than mere mention here.

The effect of sewage has also attracted attention. It has been claimed by a French writer that some river waters have been made clearer and better adapted to certain manufacturing uses by a slight sewage contamination. Numerous sanitary investigations have shown that waters contaminated by sewage to a very dangerous degree are often of exceptional pellucidity and sparkling clearness. In experiments on a clayey garden soil from the Connecticut Valley, which agitated with pure water retains the suspended matter with great tenacity, I found that minute quantities of sewage soon rendered it as clear as the very clearest natural waters, while the portion in pure water has a visible opalescence after six years' standing, the last three of which have been in a dark, quiet closet. "The Broad street pump," famous in sanitary literature, had great local popularity because of the sparkling clearness of its waters. Well-to-do people living miles away sent their servants with jugs for it, as a choice drinking water, because of this clearness, until it was closed by the authorities, after its sewage-contaminated waters had spread cholera into a multitude of homes, several hundred dying in a single month.

I think that where clay is precipitated by salts in the presence of organic matter which is partly in solution and partly in suspension (as sewage), the clay carries down with it much of the organic matter, probably in a sort of chemical combination similar to the "lake" formed by salts of alumina with dye-stuffs in dyeing.

* Since the reading of this paper it has been reported to me from several sources that even horses and mules in countries with alkaline waters soon learn that muddied waters are not alkaline, and choose muddy water for drinking

The water stored in reservoirs for the supply of cities sometimes in summer becomes offensive to the taste and smell, the cause being usually referred to the solution and decay of organic matter in the source of supply, or the growth and decay of low organisms in the reservoirs and distr buting pipes. In New Haven, where I have carefully watched the phenomena in connection with the temperature and clearness of the water, on several occasions when such smell and taste was occurring heavy summer storms have roiled the waters, and each time this has taken place the special smell and taste have disappeared with the advent and precipitation of the suspended mud.

Water containing a very small proportion of organic albuminoid will putrefy and stink, and if this be mixed with sea-water or brackish water it becomes much more offensive to the smell than in fresh water, and there is an evolution of sulphureted hydrogen along with that of the putrid organic gases. I have experimented with dilute solutions of the albuminoids dissolved from marsh vegetation and from wood. If such dilute solution be mixed during the putrefactive stage with roiled water, a new set of phenomena occurs, and a considerable of the organic matter goes down with the clay as it subsides. I have not followed this up with satisfactory examinations of the precipitate, but some of the samples have strongly the odor of the offensive "blue mud" in the shallow harbors of our seaport towns. The sanitary bearings of this I alluded to in a paper a few years ago, but the facts have doubtless also their geological significance, and probably have something to do with the "mud-lump" phenomena at the mouth of the Mississippi. The occurrence of these "mud lumps" only in shoal salt or brackish water, and never in the fresh water swamps, and the evolution of organic gases and of sulphureted hydrogen, are at least suggestive, and other phenomena relating to them are in accordance with some of the observations made in the experiments on the mutual reactions of decaying organic matter, brackish water, and suspended clay.

The effect of the common mineral acids on suspended clays is even more rapid than that of the salts. Some turbid waters are cleared more in five or ten minutes by the addition of sulphuric, nitric, or chlorohydric acids, or, better, mixtures of these, than in as many weeks or even months in pure water.

A considerable number of experiments have been made with acid similar to those described with salt by beginning with a stronger solution and reducing its strength when the material had settled, by decanting the clear portions, and adding an equal volume of distilled water. I may say here that the most of these experiments have been conducted in precipitating flasks made for the purpose, of hard glass, about a foot high, three inches in diameter at the base and one at the top. In some cases the whole of a portion of clay was treated; in others, after a watery suspension had stood several days, and when all the coarser particles had subsided, the upper part would be decanted, thoroughly mixed to insure uniformity, then divided into several portions for treatment in different ways for comparison with each other.

With those treated with acids the usual course has been to begin with clay in an acid or mixture of acids of known strength, amounting to 20 to 60 per cent. of the whole volume of the fluid under experiment, allowing it to settle, decant a given amount of the clear portion, and add the same amount of distilled water, the strength of the acid in the successive dilutions being calculated and the successive dilutions recorded.

With the mineral acids it has been the rule that at first the flocculation and precipitation are very rapid, the rapidity but slightly diminishing with great reductions of strength until the proportion of acid became very small; then there would be a marked increase in time needed, then finally and suddenly the subsiding would be as slow or slower than in pure water. One of the specimens exhibited to the Academy is of a fine clay from Hartford, Conn. I began with 60 per cent. nitromuriatic acid for, twelve successive dilutions and until the proportion of acid was by calculation almost infinitesimal (one part in several thousand of the liquid) one or two days was amply sufficient for clearing; the thirteenth cleared in nine days; the fourteenth in fourteen weeks; the fifteenth, after standing two and a half years, is still very obviously opalescent.

Two others are exhibited in which the behavior was similar, only the degree of dilution was not so great. One has stood thirty and the other thirty-two months, and the opalescence in each case is more marked than with companion portions which were begun in pure water only. In each case the precipitation was comparatively rapid until the proportion of acid amounted to less than one part in a thousand of the liquid, and in some the final long-continued suspension was only reached when the amount was very much less.

In some of the samples iridescent films or spicules have formed in the liquid, very like silica separated from solutions of dissolved glass; but the glass of the flasks used purported to be hard chemical glass, and I cannot test the samples without agitating them and thus bringing the experiments to a close. Similar glasses similarly treated have not become decomposed, and at present I think that the iridescent material is silica derived, not from the decomposition of the glass, but rather from a portion of the clay which may have undergone similar decomposition.

In the course of the experiments with acid solutions, as they reached a sufficient degree of dilution of acid and purity of water, there were the same picking up and suspension of material that was observed in the experiments with salt.

Caustic alkalies, potash, soda, and ammonia have also been used. Some authorities have stated that while acids and salts hasten sedimentation, alkalies check it and may even suspend it indefinitely. My experiments do not confirm this, but show rather the contrary effect. For example, the same Hartford clay which was used in experiments with salts and acids was used also with alkalies. A single illustration will suffice. Beginning with a solution containing one-half of 1 per cent. of pure caustic potash, the sedimentation was very much more rapid than in a similar portion in pure water, but not so rapid as samples with acids or salts. Operating on weaker and weaker solutions by successive decantations as before described, it would become nearly clear in twelve hours, when the proportion of potash in the solution was only .0008. When it was reduced to .0002 the behavior was then much as in pure water, and the sample is not yet entirely clear, after more than two years' standing.

So far as my experiments go, fine clays are precipitated from alkaline solutions more quickly and more completely than from pure water, no matter how dilute the solution.

When very fine soils, rich in organic matter (as, for example, some of the rich prairie bottom lands of Illinois), are agitated with water, there is much tendency, if the vessels are kept in the light, for a growth of confervoid algæ year after year, the decaying remains of which, diffused through the water, go down mostly with the clay, if agitated; but the solutions never become clear of the very light flocculent organic matter from the decaying algæ, now rising and now falling with changes of temperature and other conditions. Fresh agitation and settling may render it nearly clear for a time, but a new crop will spring up, its decayed remains to behave in the same way.

In experiments with neutral organic substances—crystalloids, like cane-sugar, and colloids, like extract of peat—there has been no law deduced; some hasten precipitation, others retard it, still others seem indifferent. I have experimented on the sugars along with yeast to observe the relations to fermentation, but this opens up a new set of reactions which I will not discuss here, the phenomena varying with the intensity of the action.

Early in the investigation I was led to believe that the behavior of the suspended particles of solids was different in the presence of crystalloid substances, as a class, from that in the presence of colloids, but at the present state of the investigation this is not proven.

The statements of some investigators lead to the inference that the rapidity of sedimentation is correlated with the activity of the "Brownian movements," and I have studied this part of the subject with especial interest.

The rapidity of the subsidence of the particles visible with the microscope appears to be related to this, and those substances which retard the "Brownian movements" hastens the precipitation. This applies to the fine grains of sand, flocculent clays, and such inert substances as pulverized charcoal. But I do not believe that the "Brownian movements" are continuously active in a liquid otherwise at rest, kept in a dark, quiet place, and where the changes of temperature are slight and take place very slowly. The conditions where these movements can be observed are necessarily those where various forms of radiant energy are manifest, and these are the probable active cause of the movements. It seems to me that where suspended clays are kept in the dark, and where there is little variation in temperature, we can hardly look to the energy of the "Brownian movements" as the active cause of the resistance to gravity and suspension of the heavier solid in the lighter liquid.

The later opalescence, which lingers so long, as well indeed as much of the more visible clay earlier, does not exist in the liquid as separately visible particles even with the microscope. All the microscopically visible particles settle relatively early in the experiment; the later opalescence is from ultramicroscopic materials. This is more visible in the sunlight than in ordinary diffused light, and shows the path of a beam of sunlight through it very strongly when the amount suspended is very slight indeed. The clearest natural waters, I have found, are not optically pure, but some appear to be without the opalescence that I have described from suspended clays.

Those portions of clay that remain long suspended, and are without separately visible particles, seem to me to be in a condition analogous to that of a colloid, reminding one of diluted gelatinous silica or diluted boiled starch. In many respects the behavior of that portion of a clay which will not settle to the bottom of a vessel a few inches deep in several days of quiet is that of a colloid. Prof. S. W. Johnson, whose knowledge of soils in their chemical and agricultural relations is so extensive, and who has been acquainted with these experiments during their progress, first suggested to me that the phenomena might be essentially chemical and to relate to the state of hydration of the clays.

Following this up, it seems to me probable that there may exist a series of hydrous silicates of alumina and iron, holding very feebly different amounts of water, and having different properties, so far as their relation to water is concerned, some swelling up in water more than others, and diffusible in it (as colloids) with different degrees of facility, and that acids, salts, heat, and other conditions change these states of hydration, and thus change the behavior of the suspended material towards water; that some which exist in pure water at one temperature are destroyed by another temperature, or by acids, salts, &c.

There are many indications that this is the case. The use of lime in agriculture for drying heavy, wet, clayey lands was known long before underdraining was extensively practiced. The burning of clays and other operations in agriculture may have their practical basis in the same chemical properties of clay. The tendency of many, and indeed most, clays when diffused in water to arrange themselves in layers or strata in the liquid suggests the same thing, these different strata representing different chemical compounds of a series. With some of the finer sedimentary clays it is not uncommon to have as many as six or eight such layers in the turbid liquid, and these probably represent different weak chemical compounds, settling with different degrees of rapidity, and more or less colloid, or, if not soluble as a colloid, having different degrees of attraction towards the water. When some of these are slowly evaporated at low temperatures, the resulting solid is very bulky at first, colloidal in appearance, shrinking enormously on drying, and after being dried behaving very differently towards water. The effects of freezing and thawing are also suggestive.

In short, there are many indications that clays (and perhaps other similar compounds) under certain conditions in water enter into new chemical combinations with the water, forming compounds having some colloidal characters, which compounds are stable only under a very limited range of conditions, but which are nevertheless of vast importance in the economy of nature. My own experiments have extended to a relatively small number of substances, but chemical literature of recent years mentions colloidal forms of various metallic oxides, and my experiments may illustrate but narrow phases of much wider-reaching phenomena.

Geological suggestions other than those already noted are sufficiently abundant, and have occurred all along the line of the investigation: suggestions pertaining to the segregation of veins, the phases of lamination in certain slates, the hardening of comminuted corals and shells into limestones, the effect of the alkaline salts evolved in the decomposition of rocks, the action and effects of alternately hot and cold waters on rocks and in veins—these and many other possible relations. The experiments were begun with very limited objects, but as they have gone on and widened with time they have suggested very many possibilities.

NATIONAL ACADEMY OF SCIENCES.

# FOURTH MEMOIR.

# UPON THE FORMATION OF A DEAF VARIETY OF THE HUMAN RACE.

BY

ALEXANDER GRAHAM BELL

# UPON THE FORMATION OF A DEAF VARIETY OF THE HUMAN RACE.

*A PAPER PRESENTED TO THE NATIONAL ACADEMY OF SCIENCES AT NEW HAVEN, NOVEMBER 13, 1883.*

## Introductory Remarks.

The influence of selection in modifying our breeds of domestic animals is most marked, and it is reasonable to suppose that if we could apply selection to the human race we could also produce modifications or varieties of men.

But how can we ascertain the susceptibility of the human race to variation produced by selection? We cannot dictate to men and women whom they shall marry, and natural selection no longer influences mankind to any great extent.

We can see around us everywhere evidences of the transmission by heredity of characteristics, both desirable and undesirable, but at first sight no general selective influence appears to be at work to bring about the union in marriage of persons possessing the same congenital peculiarities. On the contrary, sexual attraction often appears to operate after the manner of magnetical attraction—"unlike poles attract, like poles repel." Strong, vigorous, and robust men naturally feel a tenderness for weak, delicate, and fragile women, and are generally repelled by physical strength and masculine traits in one of the opposite sex. Even in such characteristics as the color of the hair and eyes, it often appears that unlikes attract.

Certain diseases are known to be liable to transmission by heredity. But we do not find epileptics marrying epileptics, or consumptives knowingly marrying consumptives. Even though persons afflicted with the same hereditary disease were to intermarry for a number of successive generations, it is doubtful whether any permanent variety of the race could be formed in this way, for the increased tendency to disease inherited by the offspring would probably cause a greater tendency to premature death and ultimately occasion the extinction of the variety.

On the other hand, it is reasonable to suppose that the continuous intermarriage of persons possessing congenital defects not associated with diminished vitality or vigor of constitution would result after a number of generations in the production of a vigorous but defective variety of the race. For instance, the absence of coloring matter from the skin and hair is a defect occasionally found among human beings, and we may learn from the success of attempts to propagate Albinism among animals, that we would probably produce a pink-eyed, white-haired variety of the human race by causing Albinos to marry one another; but this is only speculation. We cannot control the marriages of men as we can the breeding of animals, and at first sight there seems to be no way of ascertaining how far human beings are susceptible of variation by selection.

Such a conclusion, however, would be incorrect; and I desire to direct attention to the fact that in this country *deaf-mutes marry deaf-mutes.*

An examination of the records of some of our institutions for the deaf and dumb reveals the fact that such marriages are not the exception, but the rule. For the last fifty years there has been some selective influence at work which has caused, and is still causing, the continuous selection of the deaf by the deaf in marriage.

If the laws of heredity that are known to hold in the case of animals also apply to man, the intermarriage of congenital deaf-mutes through a number of successive generations should result in the formation of a deaf variety of the human race.

On the other hand, if it can be shown that congenitally deaf persons marry one another without any greater liability to the production of deaf offspring than is to be found among the people at large, then it will be evident that we cannot safely apply to man the deductions that have been drawn from experiments upon animals.

There are good grounds for the belief that a thorough investigation of the marriages of the deaf and the influence of these marriages upon the offspring will afford a solution of the problem, "To what extent is the human race susceptible of variation by selection?"

Although the statistics I have been able to collect are very incomplete, I have ventured to bring the subject to the attention of the Academy, in the hope that the publication of the results so far obtained may lead to the completion of the statistics.

# Chapter I.

## UPON THE MATERIALS FOR THE FORMATION OF A DEAF VARIETY OF THE HUMAN RACE AT PRESENT EXISTING IN AMERICA.

The first difficulty encountered in the inquiry is that the published reports of our institutions for the deaf and dumb contain very little information bearing upon the subject, but, judging from the questions that are asked of the parents or guardians of the pupils, there must be among the unpublished records of our institutions an immense collection of valuable facts relating to heredity at present inaccessible to the public. Many of the reports of the institutions contain little more of interest in this connection than a catalogue of the pupils. The mere lists of names, however, become of value by directing attention to the fact that among the pupils who have been admitted to many of our institutions, numerous groups of deaf-mutes are to be found who have the same surname.

No one would be surprised by the moderate recurrence of such common names as "Smith" or "Brown" or "Johnson"—as the recurrences might be accidental, and have no other significance than to indicate the prevalence of these names in the community at large. But can it be accidental that there should have been admitted into one institution eleven deaf-mutes of the name of "Lovejoy," seven of the name of "Derby," and six of the name of "Mayhew." What interpretation shall we place upon the fact that groups of deaf-mutes are to be found having such names as "Blizzard," "Fahy," "Hulett," "Closson," "Brasher," "Copher," "Gortschalg," &c.? Such names are by no means common in the community at large, and the inference is irresistible that in many cases the recurrences indicate blood-relationship among the pupils.

An examination of a number of institution reports shows that these recurrences are altogether too numerous to be entirely accidental, and we are forced to conclude, (1) that deafness runs in certain families, (2) that these families are very numerous, and (3) that they are to be found in all parts of the United States.

The following list of recurring surnames, taken from the 1877 report of the American Asylum for the Education of the Deaf and Dumb (Hartford, Conn.), will show how numerous these recurrences are among the pupils of our older institutions:

TABLE I.—*Recurrence of surnames among 2,106 pupils admitted between the years 1817 and 1877.*

American Asylum for the education of deaf-mutes, Hartford, Conn.

Names occurring 25 times: Smith.
Names occurring 20 times: Allen.
Names occurring 17 times: Brown.
Names occurring 13 times: Campbell, Davis.
Names occurring 12 times: White.
Names occurring 11 times: Clarke, Johnson, Lovejoy.
Names occurring 10 times: Small.
Names occurring 9 times: Fuller, Green, West, Williams, Wood.
Names occurring 8 times: Bailey, Bartlett, Perkins, Richardson, Rogers, Wright.
Names occurring 7 times: Derby, Jack, Marsh, Martin, Merrill, Thomas.
Names occurring 6 times: Berry, Butler, Hawley, Marshall, Mayhew, Morse, O'Brien, Rowe, Russell, Stevens, Swett, Taylor, Tripp.
Names occurring 5 times: Andrews, Ball, Barnard, Blizzard, Chapman, Cook, Curtis, Dennison, Fisk, French, Holmes, Howe, Jackson, Kimball, Meacham, Newcombe, Packer, Parker, Pease, Porter, Reed, Slocum, Sullivan, Tilton, Webster, Wilson, Young.
Names occurring 4 times: Baker, Bennett, Bigelow, Bishop, Burbee, Chandler, Ellis, Emerson, Fahy, Fisher, Foster, Gilbert, Hammond, Hill, Holt, Hulett, Hull, Jellison, Jones, Kendall, Kennedy, Ladd, Luce, Marr, Mayberry, Miller, Morgan, O'Neill, Page, Parsons, Prior, Quinn, Robbins, Ryan, Scovell, Stone, Strong, Stuart, Thompson, Turner, Wakefield, Ward, Welch, Wells, Wiswell.
Names occurring 3 times: Abbott, Acheson, Allard, Atkins, Badger, Baldwin, Barnes, Barrett, Blakely, Bliss, Boardwin, Briggs, Bruce, Burnham, Cantlon, Carpenter, Carter, Clossen, Clough, Cobb, Cummins, Daniels, Dennison, Drown, Dudley, Edwards, Fish, Frank, Goodrich, Gray, Haley, Haskell, Holden, Hunter, Ingraham, Jordan, Lafferty, Lambert, Larabee, Livingston, Lombard, Lyman, Macomber, Mahoney, Mann, McCarty, Mitchell, Moore, Morrison, Mowry, Murphy, Nelson, Newton, Noyes, Osgood, Palmer, Perry, Platt, Pratt, Prescott, Randall, Reynolds, Robertson, Sage, Sawyer, Sherman, Sloane, Stebbins, Stevenson, Taft, Titcombe, Town, Trask, Wardman, Watson, Wentworth, Wheeler, Whitcomb, Wilkins, Winslow, Woodward.
Names occurring 2 times: These are too numerous to be quoted here. There are two hundred and fourteen of them.

The following tables show that the pupils referred to above constitute more than 63 per cent. of the total number of pupils admitted:

TABLE II.—*Recurrence of surnames among the pupils of the American Asylum for deaf-mutes, Hartford, Conn.* (1877 *Report.*)

| | No. of pupils represented. |
|---|---|
| 764 names occur 1 time | 764 |
| 214 names occur 2 times | 428 |
| 81 names occur 3 times | 243 |
| 45 names occur 4 times | 180 |
| 27 names occur 5 times | 135 |
| 13 names occur 6 times | 78 |
| 6 names occur 7 times | 42 |
| 6 names occur 8 times | 48 |
| 5 names occur 9 times | 45 |
| 1 name occurs 10 times | 10 |
| 3 names occur 11 times | 33 |
| 1 name occurs 12 times | 12 |
| 2 names occur 13 times | 26 |
| 1 name occurs 17 times | 17 |
| 1 name occurs 20 times | 20 |
| 1 name occurs 25 times | 25 |
| 1,171 | 2,106 |

TABLE III.—*Showing recurrence of surnames and percentages of the whole.*

(American Asylum, 1877 Report.)

| Number of surnames. | Number of pupils represented. | Percentage of the whole. |
|---|---|---|
| 764 names occur once | 764 | 36.3 |
| 214 names occur twice | 428 | 20.3 |
| 193 names occur three or more times | 914 | 43.4 |
| 1,171 | 2,106 | 100.0 |

The American Asylum, at Hartford, Conn., was established in 1817, under the patronage of Congress, as a school to be open to all the deaf-mutes of the United States. As new centers of instruction sprang up the supply of pupils from the more distant States was practically cut off, and the institution is more representative of the New England States than of the whole country.

This will be obvious from the following table (Table IV), which gives a synopsis of 2,109 cases admitted to the asylum before May, 1877, classified according to residence.

TABLE IV.—*Classification of pupils in respect to residence.*

(American Asylum, 1877 Report.)

| Where from. | No. | Where from. | No. |
|---|---|---|---|
| Maine | 336 | Connecticut | 362 |
| New Hampshire | 214 | California | 2 |
| Vermont | 233 | Pennsylvania | 14 |
| Massachusetts | 731 | Maryland | 5 |
| Rhode Island | 67 | New York | 34 |
| New Jersey | 7 | Illinois | 2 |
| District of Columbia | 2 | Michigan | 1 |
| Virginia | 11 | Wisconsin | 1 |
| North Carolina | 4 | Ohio | 6 |
| South Carolina | 19 | British Provinces | 25 |
| Georgia | 27 | West Indies | 1 |
| Alabama | 4 | West Virginia | 1 |
| Louisiana | 1 | | |
| Texas | 1 | | 2,109 |
| Indiana | 1 | | |

In order to show that the numerous recurrence of surnames is not confined to the deaf-mutes of the New England States nor to the pupils of our oldest institutions, I give a list of recurring surnames taken from the 1882 report of the Illinois Institution.

This institution, although only opened in 1846, is now the largest of its kind in the world, and it may fairly be taken as representative of a large section of country in the West.*

TABLE V.—*Recurrence of surnames among* 1,620 *pupils admitted between the years* 1846 *and* 1882.

(Illinois Institution for the Deaf and Dumb, Jacksonville, Ill.)

Names occurring 18 times: Smith.

Names occurring 16 times: Brown.

Names occurring 10 times: Anderson, Miller.

Names occurring 9 times: Edwards, Wilson.

Names occurring 8 times: Johnson.

* As the American Asylum and Illinois Institution may be taken as representative institutions, I present in an appendix a critical analysis of all the cases recorded in the reports referred to. (See Tables A to N, in the appendix.)

For this analysis I am indebted to Mr. Franck Z. Maguire, of Washington, D. C., and I have personally verified his results.

Names occurring 7 times: Davis, Jones.
Names occurring 6 times: Kelly, Mitchell, Moore, Welch, White, Williams, Wright.
Names occurring 5 times: Adams, Allen, Clark, Hall, Lee, Long, Stephens, Taylor, Thompson, Wolf.
Names occurring 4 times: Bailey, Barnes, Berry, Cox, Gunn, Harris, Hixon, Huffman, Jacoby, James McClelland, Murphy, Sturgeon, Sullivan, Townsend, Walker.
Names occurring 3 times: Ammons, Baker, Ballard, Boyd, Brasher, Brooks, Buckley, Campbell, Carroll, Chamberlain, Conn, Copher, Crawford, Darnell, Doyer, Ford, Fuller, Gibson, Goodner, Goodwin, Gortschalg, Gray, Harper, Hill, Keil, Kennedy, Laughlin, McFarland, McGary, McLean, McNeal, Merrill, Morgan, Neilson, Nichols, Simmonds, Sterling, Stewart, Stout.
Names occurring 2 times: These are too numerous to be quoted here. There are 150 of them.

The following tables show that the pupils referred to above constitute more than 41 per cent. of the whole number of pupils admitted:

TABLE VI.—*Recurrence of surnames among the pupils of the Illinois Institution for the Deaf and Dumb.*

(1882 Report.)

| | | No. of pupils represented. |
|---|---|---|
| 953 names occur | 1 time | 953 |
| 150 names occur | 2 times | 300 |
| 39 names occur | 3 times | 117 |
| 16 names occur | 4 times | 64 |
| 10 names occur | 5 times | 50 |
| 7 names occur | 6 times | 42 |
| 2 names occur | 7 times | 14 |
| 1 name occurs | 8 times | 8 |
| 2 names occur | 9 times | 18 |
| 2 names occur | 10 times | 20 |
| 1 name occurs | 16 times | 16 |
| 1 name occurs | 18 times | 18 |
| 1,184 | | 1,620 |

TABLE VII.—*Recurrence of surnames and percentages of the whole.*

(Illinois Institution, 1882 Report.)

| Number of surnames. | Number of pupils represented. | Percentage of the whole. |
|---|---|---|
| 953 names occur once | 953 | 58.8 |
| 150 names occur twice | 300 | 18.5 |
| 81 names occur three or more times | 367 | 22.7 |
| 1,184 | 1,620 | 100.0 |

The recurrence of numerous surnames among the pupils of very many of our institutions for the deaf and dumb renders it highly probable that *a considerable proportion of the deaf-mutes of the country belong to families containing more than one deaf-mute, and hence possess hereditary tendencies to deafness.*

The same conclusion is still more forcibly suggested to the mind by a perusal of the few institution reports that record the deaf-mute relatives of the pupils. The following tables (Tables VIII, IX, X, XI, XII) bearing upon this subject have been compiled from the 1877 Report of the

American Asylum.* They show that of 2,106 pupils admitted to that institution, 693, or nearly 33 per cent., were known to have deaf-mute relatives. The significance of this becomes more apparent when we find that in the majority of these cases the pupils have more than one relative deaf and dumb, while in a few cases as many as fifteen deaf-mute relatives are recorded.

TABLE VIII.—*Deaf and dumb relatives of the pupils of the American Asylum for Deaf-Mutes, from the 1877 Report.*

| Pupils having deaf and dumb relatives. | Deaf and dumb relatives of pupils | Pupils having deaf and dumb relatives. | Deaf and dumb relatives of pupils. |
|---|---|---|---|
| 1 | 1 great grandfather. | 31 | 2 sisters. |
| 1 | 1 grandfather. | 3 | 3 sisters. |
| 1 | 1 grandfather, father, mother and other relatives. | 1 | 4 sisters. |
| 1 | 1 grandfather, father, 3 children, and other relatives. | 7 | 1 sister and 1 cousin. |
| 1 | 1 grandfather, father, and brother. | 1 | 1 sister, 1 cousin, and 1 uncle. |
| 1 | 1 grandfather, father, and sister. | 1 | 1 sister and 3 cousins. |
| 6 | father and mother | 2 | 1 sister, 3 cousins, and 1 uncle. |
| 1 | father, mother, and 1 brother. | 1 | 1 sister and 4 cousins. |
| 2 | father, mother, and 2 brothers. | 1 | 1 sister, 6 cousins, and 1 uncle. |
| 1 | father, mother, and 2 sisters. | 1 | 1 sister and 1 uncle. |
| 4 | father, mother, 1 brother, and 1 sister. | 1 | 1 sister and 1 aunt. |
| 1 | father, mother, 2 brothers, and 1 sister. | 1 | 1 sister, 2 aunts and other relatives. |
| 1 | father, mother, 1 brother, and 2 sisters. | 2 | 1 sister and other relatives. |
| 1 | father, mother, 1 brother, and 5 uncles and aunts. | 1 | 1 sister and 4 other relatives. |
| 2 | father, mother, 1 sister, 1 uncle, and 1 aunt. | 2 | 1 sister and 11 other relatives. |
| 2 | father, mother, 2 brothers, and 2 uncles. | 1 | 1 sister and 7 other relatives. |
| 1 | father, mother, 2 sisters, and 1 uncle. | 7 | 2 sisters and 1 cousin. |
| 2 | father, mother, 1 brother, 1 sister, and 1 uncle. | 1 | 2 sisters and 2 cousins. |
| 1 | father, mother, and 1 cousin. | 1 | 2 sisters and 3 cousins. |
| 1 | father, son, 1 sister, 2 nephews, and 5 other relatives. | 3 | 2 sisters and 1 second-cousin. |
| 1 | father, 2 sisters, and other relatives. | 141 | 1 brother. |
| 1 | father, 1 brother, and 1 sister. | 17 | 1 brother and 1 sister. |
| 3 | father, 1 brother, 1 sister, and 1 cousin. | 12 | 1 brother and 2 sisters. |
| 2 | father, 4 brothers, 1 sister, and 1 cousin. | 8 | 1 brother and 3 sisters. |
| 1 | father, 3 brothers, 2 sisters, and 1 cousin. | 6 | 1 brother, 1 sister, and 1 cousin. |
| 1 | mother and 1 brother. | 2 | 1 brother, 2 sisters, and 2 cousins. |
| 1 | mother and 2 sisters. | 1 | 1 brother, 1 sister, and 3 cousins. |
| 2 | mother, 1 brother, and 1 sister. | 1 | 1 brother, 1 sister, and 1 second-cousin. |
| 1 | mother, 1 brother, 2 sisters, and 1 cousin. | 2 | 1 brother, 1 sister, 1 cousin, and 1 uncle. |
| 1 | mother, 2 brothers, 1 sister, and 1 cousin. | 4 | 1 brother and 1 cousin. |
| 2 | mother and 1 uncle. | 1 | 1 brother and 3 cousins. |
| 1 | mother and 2 uncles. | 1 | 1 brother and 4 cousins. |
| 6 | 1 child. | 1 | 1 brother, 4 cousins, and other relatives. |
| 2 | 1 child and 1 brother. | 1 | 1 brother and 1 aunt. |
| 3 | 1 child and 1 sister. | 1 | 1 brother and 1 niece. |
| 1 | 1 child and 2 sisters. | 2 | 1 brother and 2 nephews. |
| 1 | 1 child and 1 cousin. | 1 | 1 brother and other relatives. |
| 1 | 2 children and 1 brother. | 1 | 1 brother and 7 other relatives. |
| 1 | 2 children, 1 brother, and 2 sisters. | 1 | 1 brother, 1 sister, and 1 second-cousin. |
| 4 | 3 children. | 26 | 2 brothers. |
| 1 | 3 children and 1 brother. | 34 | 2 brothers and 1 sister. |
| 1 | 3 children, 1 brother, and 1 cousin. | 11 | 2 brothers and 2 sisters. |
| 1 | 3 children and 1 cousin. | 4 | 2 brothers and 1 cousin. |
| 1 | 3 children and other relatives. | 2 | 2 brothers, 2 cousins, and 2 uncles. |
| 1 | 4 children. | 2 | 2 brothers, 1 sister, and 2 cousins. |
| 1 | 5 children and 1 brother. | 1 | 2 brothers, 2 sisters, 1 uncle, and 1 aunt. |
| 1 | 5 children and 2 brothers. | 1 | 2 brothers, 2 sisters, and 11 other relatives. |
| 1 | 5 children, 1 brother, and 2 sisters. | 6 | 3 brothers. |
| 129 | 1 sister. | 10 | 3 brothers and 1 sister. |
| | | 2 | 3 brothers and 3 sisters. |
| | | 1 | 3 brothers, 1 sister, and 2 second-cousins. |
| | | 3 | 4 brothers. |

* See "The sixty-first annual report of the directors and officers of the American Asylum, at Hartford, for the education and instruction of the deaf and dumb," presented to the asylum May 15, 1877, pp. 12-98.

TABLE VIII.—*Deaf and dumb relatives of pupils of American Asylum for Deaf-Mutes, &c.*—Continued.

| Pupils having deaf and dumb relatives. | Deaf and dumb relatives of pupils. | Pupils having deaf and dumb relatives. | Deaf and dumb relatives of pupils. |
|---|---|---|---|
| 7 | 4 brothers and 2 sisters. | 1 | 1 uncle and 1 aunt. |
| 1 | 5 brothers. | 1 | 2 uncles. |
| 2 | 5 brothers and 1 sister. | 1 | 1 niece. |
| 22 | 1 cousin. | 1 | 1 nephew. |
| 1 | 1 cousin and 1 uncle. | 1 | 2 nephews, 2 nieces, and 1 other relative. |
| 4 | 2 cousins. | 6 | 1 second-cousin. |
| 1 | 2 cousins and 1 aunt. | 1 | 2 second-cousins. |
| 1 | 3 cousins. | 1 | 1 third-cousin. |
| 1 | 3 cousins and 3 great-uncles. | 1 | 1 relative. |
| 1 | 3 cousins and 2 uncles. | 2 | 2 relatives. |
| 1 | 3 cousins and 2 other relatives. | 1 | Relatives. |
| 2 | 4 cousins. | 1 | 4 relatives. |
| 2 | Cousins. | 1 | 4 remote relatives. |
| 1 | Several cousins. | 1 | 6 relatives. |
| 3 | 1 aunt. | 693 | |
| 6 | 1 uncle. | | |

| | |
|---|---|
| Pupils having deaf-mute relatives | 693 |
| Pupils recorded as sporadic cases | 1,413 |
| Total | 2,106 |

TABLE IX.—*Deaf-mute relatives of the pupils.*

(American Asylum for Deaf-Mutes. Report for 1877.)

1 pupil had one or more great-grandparents deaf and dumb.
5 pupils had one or more grandparents deaf and dumb.
47 pupils had one or more parents deaf and dumb.
29 pupils had one or more children deaf and dumb.
593 pupils had one or more brothers or sisters deaf and dumb.
100 pupils had one or more cousins deaf and dumb.
38 pupils had one or more uncles or aunts deaf and dumb.
1 pupil had one or more great-uncles or aunts deaf and dumb.
48 pupils had one or more distant relatives deaf and dumb.

TABLE X.—*Deaf-mute children of the pupils.*

(American Asylum for Deaf-Mutes. Report for 1877.)

29 pupils had 1 or more children deaf and dumb.
15 pupils had 2 or more children deaf and dumb.
13 pupils had 3 or more children deaf and dumb.
4 pupils had 4 or more children deaf and dumb.
3 pupils had 5 or more children deaf and dumb.

TABLE XI.—*Deaf-mute brothers and sisters of the pupils.*

(American Asylum for Deaf-Mutes. Report for 1877.)

593 pupils had 1 or more brothers and sisters deaf and dumb.
271 pupils had 2 or more brothers and sisters deaf and dumb.
116 pupils had 3 or more brothers and sisters deaf and dumb.
51 pupils had 4 or more brothers and sisters deaf and dumb.
15 pupils had 5 or more brothers and sisters deaf and dumb.
11 pupils had 6 or more brothers and sisters deaf and dumb.

TABLE XII.—*Showing number of pupils having one or more deaf-mute relatives.*

(American Asylum for Deaf-Mutes. Report for 1877.)

693 pupils had 1 or more relatives deaf and dumb.
374 pupils had 2 or more relatives deaf and dumb.
224 pupils had 3 or more relatives deaf and dumb.
120 pupils had 4 or more relatives deaf and dumb.
65 pupils had 5 or more relatives deaf and dumb.
35 pupils had 6 or more relatives deaf and dumb.
15 pupils had 7 or more relatives deaf and dumb.
9 pupils had 8 or more relatives deaf and dumb.
4 pupils had 10 or more relatives deaf and dumb.
3 pupils had 15 or more relatives deaf and dumb.

Without going into detail, the results may be noted of an examination of a few other institution reports* where the deaf-mute relatives are recorded.

TABLE XIII.—*Proportion of the deaf and dumb having deaf-mute relatives.*

| Institutions. | Total number of pupils. | Number of pupils having deaf-mute relatives. | Percentage of pupils having deaf-mute relatives. |
|---|---|---|---|
| American Asylum | 2,106 | 693 | 32.9 |
| New York Institution | 1,165 | 380 | 32.6 |
| Ohio Institution | 560 | 166 | 29.6 |
| Indiana Institution | 283 | 103 | 36.4 |
| Illinois Institution | 1,620 | 356 | 21.7 |
| Texas Institution | 89 | 21 | 23.6 |
| Total | 5,823 | 1,719 | 29.5 |

The above table shows us that out of 5,823 deaf-mutes taken from different parts of the country no less than 1,719, or 29½ per cent., were known to have relatives deaf and dumb.

If this proportion holds for the whole country, we must have in the United States about 10,000 deaf-mutes who belong to families containing more than one deaf-mute.†

It is to be feared that the intermarriage of such persons would be attended by calamitous results to their offspring.

These are not, however, the only cases in which we would anticipate that the deafness of the parents might be transmitted to the children. The lessons we have learned from the lower animals concerning heredity teach us that a certain physical peculiarity, which may normally make its appearance only sporadically here and there, may be perpetuated and rendered hereditary, by suitable selection, during a number of generations, of those individuals that happen to possess the peculiarity from birth.

* The tables relating to the deaf-mutes of Ohio, Indiana, New York, Texas, and Illinois have been compiled from the following sources:

1. Ohio. "List of pupils admitted to the Ohio Asylum previously to January, 1854." American Annals of the Deaf and Dumb, Vol. VI, pp. 101–116.

2. Indiana. "Catalogue of the pupils of the Indiana Institution from its commencement in 1843 to November 1, 1853." American Annals of the Deaf and Dumb, Vol. VI, pp. 162–169.

3. New York. "List of pupils of the New York Institution, &c., complete from May, 1818, to January, 1854." American Annals of the Deaf and Dumb, Vol. VI, pp. 195–225.

4. Texas. "List of pupils in attendance at the Texas Institution (1881)." See Exhibit A, twenty-fifth annual report of the superintendent of the Texas Institution for the Deaf and Dumb, Austin, Tex., November 1, 1881.

5. Illinois. "List of pupils of the Illinois Institution admitted between 1846 and 1882." Twenty-first biennial report of the trustees, superintendent, and treasurer of the Illinois Institution for the Education of the Deaf and Dumb. Jacksonville, Ill., October 1, 1882.

† The number is probably greater, even exceeding twelve thousand, as will be seen further on. (See Table XVII).

We have good reason, therefore, to fear that the intermarriage of congenital deaf-mutes, even though the deafness in both cases might be sporadic, would result in many cases in the production of deaf offspring. It is important, then, to arrive at some idea of the numbers of the deaf and dumb who are deaf from birth.

The Compendium of the Tenth Census of the United States shows us that there were living in this country on the 1st of June, 1880, no less than 33,878 deaf-mutes, and that "more than one-half" were congenitally deaf.*

The proportion can be obtained more exactly from an address delivered in Jacksonville, Ill., on the 29th day of August, 1882, before the tenth convention of American instructors of the deaf and dumb, by the Rev. Fred. H. Wines,† who had charge of the department of the census relating to the deaf and dumb. Pending the full publication of the census returns, the statements of Mr. Wines concerning the census of the deaf and dumb must evidently be received as authoritative.

In the address referred to Mr. Wines gave the results of an analysis of 22,472 cases from the census, from which it appears that of these deaf-mutes 12,154, or 54.1 per cent., were reported as congenitally deaf, and 10,318, or 45.9 per cent., were stated to have lost their hearing after birth.

If we apply these figures to the total mentioned in the Compendium of the Census (33,878) we find that there are probably 18,328 congenital and 15,550 non-congenital deaf-mutes in the United States.

Deductions drawn from the breeding of animals would lead us to expect that the congenitally deaf would be more likely than those who became deaf from accidental causes to transmit their defect to their offspring. Another indication pointing in the same direction is to be found in the fact that the proportion of the deaf and dumb who have deaf-mute relatives is very much greater among the congenital than among the non-congenital deaf mutes.

The following tables (Tables XIV, XV, and XVI) have been compiled from the reports of the American institutions for the deaf and dumb already referred to:

TABLE XIV.

| Name of institution. | Date of opening. | Pupils were admitted or were in attendance during the years— | Total number of pupils. | Cause of deafness. | | | Pupils recorded to have deaf-mute relatives. | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Total number admitted or in attendance. | Cause of deafness. | | |
| | | | | Congenital. | Disease or accident. | Not stated. | | Congenital. | Disease or accident. | Not stated. |
| American Asylum | 1817 | 1817–1877 | 2,106 | 973 | 1,040 | 93 | 693 | 552 | 131 | 10 |
| New York Institution | 1818 | 1818–1853 | 1,165 | 488 | 432 | 245 | 380 | 287 | 74 | 19 |
| Ohio Institution | 1829 | 1829–1853 | 560 | 208 | 268 | 81 | 166 | 118 | 32 | 16 |
| Indiana Institution | 1844 | 1844–1853 | 283 | 149 | 124 | 10 | 103 | 72 | 31 | ...... |
| Illinois Institution | 1846 | 1846–1882 | 1,620 | 418 | 947 | 255 | 356 | 194 | 120 | 42 |
| Texas Institution | 1857 | 1881 | 89 | 26 | 53 | 10 | 21 | 11 | 8 | 2 |
| Total | | | 5,823 | 2,262 | 2,864 | 697 | 1,719 | 1,234 | 396 | 89 |

* Compendium of the Tenth Census, Part II, page 1661.

† See Proceedings of the Tenth Convention of American Instructors of the Deaf and Dumb, Jacksonville, Ill., August, 1882, pp. 122–128, published by the Illinois Institution for the Deaf and Dumb, Jacksonville, Ill., with the twenty-first biennial report of that Institution.

TABLE XV.—*Proportion of the non congenitally deaf who have deaf-mute relatives.*

| Institutions. | Number of non-congenital deaf-mutes. | Number having deaf mute relatives. | Percentage having deaf-mute relatives. |
|---|---|---|---|
| American Asylum | 1,040 | 131 | 12.6 |
| New York Institution | 432 | 74 | 17.1 |
| Ohio Institution | 268 | 32 | 11.9 |
| Indiana Institution | 124 | 31 | 25.0 |
| Illinois Institution | 947 | 120 | 12.7 |
| Texas Institution | 53 | 8 | 15.0 |
| Total | 2,864 | 396 | 13.8 |

TABLE XVI.—*Proportion of the congenitally deaf who have deaf-mute relatives.*

| Institutions. | Number of congenitally deaf pupils. | Number having deaf-mute relatives. | Percentage having deaf-mute relatives. |
|---|---|---|---|
| American Asylum | 973 | 552 | 56.7 |
| New York Ins itution | 488 | 287 | 58.8 |
| Ohio Institution | 208 | 118 | 56.7 |
| Indiana Institution | 149 | 72 | 48.3 |
| Illinois Institution | 418 | 194 | 46.4 |
| Texas Institution | 26 | 11 | 42.3 |
| Total | 2,262 | 1,234 | 54.5 |

The above tables (Tables XIV, XV, and XVI) show that *of 2,262 congenital deaf-mutes, more than one-half—or 54.5 per cent.—had deaf-mute relatives; and that even in the case of those pupils who became deaf from apparently accidental causes,* 13.8 *per cent. had other members of their families deaf and dumb.*

If we apply these results to the total returned by the Tenth Census, we obtain the following figures (Table XVII) as a probable approximation to the number of sporadic and non-sporadic cases of deafness among the deaf-mutes of the country.

TABLE XVII.—*Estimate of the probable number of sporadic and non-sporadic cases of deafness among the deaf-mutes of the United States in the year* 1880.

| Cause of deafness. | Number who have relatives deaf and dumb. | Sporadic cases. | Total. |
|---|---|---|---|
| Congenital | 9,989 | 8,339 | 18,328 |
| Disease or accident | 2,146 | 13,404 | 15,550 |
| Total | 12,135 | 21,743 | 33,878 |

If to the estimated number of deaf-mutes who have relatives deaf and dumb we add the presumed number of sporadic cases among the congenital deaf-mutes we reach a total of 20,474 cases where the deafness would probably tend to become hereditary by intermarriage. But these are not all the cases in which we would anticipate that intermarriage might be productive of deaf offspring. The late Dr. Harvey L. Peet states, as the result of his researches,* that the hearing brothers and sisters of a deaf-mute are about as liable to have deaf children as the deaf-mute himself. It is only reasonable to assume that a tendency towards deafness exists in a family containing more than one deaf-mute, so that if hearing persons belonging to such families were to intermarry, or were to marry deaf-mutes—or if a consanguineous marriage were to take place in such a family—we would not be surprised if some of the offspring should be deaf. *In addition therefore to the 20,474 deaf-mutes referred to above, we must include the hearing and speaking members of their families before we can form an adequate conception of the number of persons who possess a predisposition towards deafness.*

It will thus be seen that we have abundant materials in the United States for the formation of a deaf variety of the human race by selection in marriage.

* American Annals of the Deaf and Dumb, Vol. VI, p. 235.

## CHAPTER II.

### MARRIAGES OF THE DEAF.

Having shown that a large proportion of the deaf and dumb possess hereditary tendencies toward deafness, the question naturally arises: "Do many of the deaf and dumb marry?"

It is the custom in some of our institutions to hold periodical reunions of former pupils, and in some cases advantage has been taken of the opportunities thus presented to obtain information concerning the marriages of the pupils, &c. An examination of the reports of the American Asylum, New York, Ohio, Indiana, and Illinois institutions, yields the following results:

TABLE XVIII.

| Name of institution. | Date of opening. | Date of report. | Total number of pupils admitted.* | Total number recorded to have married. | Percentage. |
|---|---|---|---|---|---|
| American Asylum | 1817 | 1877 | 2,106 | 642 | 30.5 |
| New York Institution | 1818 | 1854 | 1,165 | 191 | 16.4 |
| Ohio Institution | 1829 | 1854 | 560 | 56 | 10.0 |
| Indiana Institution | 1844 | 1854 | 287 | 26 | 9.1 |
| Illinois Institution | 1846 | 1882 | 1,620 | 174 | 10.7 |
| Total | | | 5,738 | 1,089 | 19.0 |

*The total number of pupils noted includes the children who were in attendance at the dates of the reports.

In the Appendix I have presented in tabular form a critical analysis of all the cases mentioned in the reports of the American Asylum and Illinois Institution, classifying the pupils according to the decades in which they were born. The labor involved has deterred me from making a similar examination of the pupils of the New York, Ohio, and Indiana institutions until more complete materials can be obtained than are to be found in reports published in 1854. The American Asylum and Illinois Institution, however, as I have stated before, may be may be taken as representative institutions, and an examination of the tables in the Appendix leads to the conclusion that *a very considerable proportion of the deaf children admitted to our institutions marry.* This will be obvious, from the following considerations:

Pupils of the American Asylum, born in the year 1840, were 37 years of age in 1877 (the date of the report), and the pupils of the Illinois Institution, born in 1840, were 42 years of age in 1882 (the date of the Illinois report), hence we may safely assume that, of the pupils of these institutions who were born before 1840, all, or nearly all, who intended to marry had married before the dates of the reports; and in most cases it is probable that the fact of marriage had been recorded. If, then, we eliminate from the totals given in the above table, all the pupils of these institutions who were born since the year 1839, we obtain the following results:

TABLE XIX.—*Proportion of the pupils of our institutions for the deaf and dumb who marry.*

| Name of institution. | Date of opening. | Date of report. | Total number of pupils born before 1840. | Total number of these recorded to have married. | Percentage. |
|---|---|---|---|---|---|
| American Asylum .......... | 1817 | 1877 | 1,100 | 522 | 47.4 |
| Illinois Institution.......... | 1846 | 1882 | 159 | 49 | 30.8 |
| Total ................ | | | 1,259 | 571 | 45.4 |

Whatever may be the exact percentage for the whole country, the indications are that *a considerable proportion of the adult deaf-mutes of the United States are married.*

INTERMARRIAGES OF THE DEAF AND DUMB.

When we attempt to form an idea of the extent to which intermarriage takes place among deaf-mutes, we are met by the difficulty of the imperfection of the institution records. In very few cases is it specifically stated that a deaf-mute has married a hearing person.* The record usually stands that the pupil has "married a deaf-mute," or that he is simply "married," leaving it uncertain whether the marriage was contracted with another deaf-mute or with a hearing person. When we eliminate all the uncertain cases we obtain from the institution reports the following results:

TABLE XX.—*Proportion of the deaf and dumb who marry deaf-mutes.*

| Name of institution. | Date of opening. | Date of report. | Total number of pupils recorded to have married. | Total number recorded to have married deaf-mutes. | Percentage. |
|---|---|---|---|---|---|
| American Asylum .......... | 1817 | 1877 | 642 | 502 | 78.2 |
| New York Institution....... | 1818 | 1854 | 191 | 142 | 74.3 |
| Ohio Institution............. | 1829 | 1854 | 56 | 39 | 69.6 |
| Indiana Institution......... | 1844 | 1854 | 26 | 21 | 80.8 |
| Illinois Institution.......... | 1846 | 1882 | 174 | 152 | 87.3 |
| Total ................ | | | 1,089 | 856 | 78.6 |

The large percentage of marriages with deaf-mutes reported from Indiana and Illinois suggests the explanation that *intermarriages among the deaf and dumb may perhaps have become more common of late years.* Both institutions are of comparatively recent origin (the one founded in 1844, the other in 1846); and the report of the Illinois Institution, which exhibits the largest proportion of deaf-mute intermarriages, contains the record of much later marriages than those mentioned in the Indiana report, for the Indiana record stops at 1854, whereas the Illinois report gives the statistics of the institution to October, 1882.

Unfortunately we are unable to ascertain from the reports the dates of the marriages. If we assume, however, that as a general rule the older deaf-mutes were married before the younger, we

*Only one case in the American Asylum and ten in the Illinois Institution. It is probable, however, that in most cases where the pupil is simply recorded as "married" the record means marriage with a hearing person.

may be able to approximate to the order of the marriages by classifying the pupils according to their period of birth. Although I have not attempted a minute classification, excepting in the cases shown in the Appendix, it is comparatively easy to arrange all the married pupils referred to above into four classes: (1) those born before 1810; (2) those born in the period 1810–1839; (3) those born in the period 1840–1859; (4) those born since the commencement of 1860. The results are shown in the following table:

TABLE XXI.

| Period of birth. | Total recorded to have married. | Total recorded to have married deaf-mutes. | Percentage. |
|---|---|---|---|
| Before 1810 | 129 | 72 | 55.8 |
| 1810 to 1839 | 715 | 577 | 80.7 |
| 1840 to 1859 | 233 | 196 | 84.1 |
| 1860 and after | 12 | 11 | 91.7 |

The number married who were born since 1859 is too small to be relied upon for a percentage. It is only to be hoped that the percentage given above is excessive. The indications are very clear, however, that *of the deaf and dumb who marry, the proportion who marry deaf-mutes has steadily increased.* This conclusion is strengthened when we find that the above result, which has been deduced from a summation of all the cases recorded in the reports of the American Asylum, New York, Indiana, Ohio, and Illinois institutions, is also true of the cases recorded in each report taken separately. This will be obvious from the following table:

TABLE XXII.

| Name of institution, with date of opening and of report. | Period of birth. | Total recorded to have married. | Total recorded to have married deaf-mutes. | Percentage. |
|---|---|---|---|---|
| American Asylum. Date of opening, 1817. Date of report, 1877. | Before 1810 | 100 | 55 | 55.0 |
| | 1810 to 1839 | 422 | 350 | 82.9 |
| | 1840 to 1859 | 120 | 97 | 80.8 |
| New York Institution. Date of opening, 1818. Date of report, 1854. | Before 1810 | 29 | 17 | 58.6 |
| | 1810 to 1839 | 162 | 125 | 77.2 |
| Ohio Institution. Date of opening, 1829. Date of report, 1854. | 1810 to 1832 | 56 | 39 | 69.6 |
| Indiana Institution. Date of opening, 1844. Date of report, 1854. | 1822 to 1836 | 26 | 21 | 80.8 |
| Illinois Institution. Date of opening, 1846. Date of report, 1882. | 1810 to 1839 | 49 | 42 | 85.7 |
| | 1840 to 1859 | 113 | 99 | 87.6 |
| | 1860 and after | 12 | 11 | 91.7 |

The only institution that gives any indication of a decrease in the proportion of pupils married to deaf-mutes is the American Asylum. The pupils born in 1859 were only 18 years of age in 1877, the date of the report, so that it is certain that a considerable number of the pupils born between 1840 and 1859 were married after the date of the report, and so escaped enumeration. It is questionable, however, whether this could affect the *proportion* who were married to deaf-mutes.

It is more reasonable to suppose that in this case the apparent decrease is real, for an entirely different method of investigation leads to a similar result. In the years 1843, 1857, 1867, and 1877 the directors of the American Asylum published in their reports the statistics of the institution, giving the names of those pupils who had married. If we assume that the pupils who were not recorded as married in the 1843 report, but who were recorded as married in the 1857 report, were married between the years 1843 and 1857, &c., we can divide the marriages reported from the American Asylum into four classes: (1) Marriages contracted before 1843, (2) marriages contracted between 1843 and 1857, (3) marriages contracted between 1857 and 1867, and (4) marriages contracted between 1867 and 1877. The results are shown in the following table:

TABLE XXIII.—*Marriages of the pupils of the American Asylum.*

| Presumed date of marriage. | Total recorded as married. | Total recorded to have married deaf-mutes. | Percentage. |
|---|---|---|---|
| Before 1843 | 143 | 95 | 66.4 |
| Between 1843 and 1857 | 217 | 175 | 80.6 |
| Between 1857 and 1867 | 131 | 110 | 84.0 |
| Between 1867 and 1877 | 151 | 122 | 80.8 |

In this case we find that although the number of pupils presumed to have married between 1867 and 1877 is greater than the number who married in the preceding decade, the proportion who married deaf-mutes is less.

It is evident from a comparison of all the tables that *of the deaf-mutes who marry at the present time not less than 80 per cent. marry deaf mutes, while of those who married during the early half of the present century the proportion who married deaf-mutes was much smaller.*

It is of course a matter of importance to ascertain to what extent congenital deaf-mutes intermarry, but unfortunately the institution records are too imperfect to allow us to draw conclusions on this point. Six hundred and fifty-four pupils of the American Asylum and Illinois Institution are each recorded simply to have "married a deaf-mute," without one word of explanation as to the name of the deaf-mute or the cause of deafness.*

It will thus be understood that the records of deaf-mute marriages are very imperfect, and it is to be hoped that some of our large institutions may publish fuller information concerning them. In the case of a deaf-mute partner it should be stated whether the deafness was congenital or not.

* Since the reading of this paper it occurred to me that some light might be thrown upon the subject by the theory of Probabilities. I therefore submitted the question to Prof. Simon Newcomb, who not only agreed with me in this idea, but was kind enough to present a solution of the problem deduced from the data given in this paper. He thinks the most probable conclusion to be this:

1. Of the congenitally deaf who married deaf-mutes one-half married congenitally deaf and one-half non-congenitally deaf.

2. Of the non-congenitally deaf who married deaf-mutes three-sevenths married congenitally deaf and four-sevenths non-congenitally deaf.

The full text of Professor Newcomb's letters will be found in Appendix Z.

I would also suggest that, wherever possible, the names of the husbands and wives of the pupils should be given, and the fact recorded as to whether they belong to families containing more than one deaf-mute or not. This is important even in the case of marriage with a hearing person, for in most of the cases of such marriages that have come under my personal observation the hearing partner belonged to a family containing deaf-mutes.

However imperfect may be the records of the marriages of the deaf it is abundantly evident, (1) *that there is a tendency among deaf-mutes to select deaf-mutes as their partners in marriage*; (2) *that this tendency has been continuously exhibited during the past forty or fifty years, and* (3) *that therefore there is every probability that the selection of the deaf by the deaf in marriage will continue in the future.*

It is evident, then, that we have here to consider, not an ephemeral phenomenon, but a case of continuous selection. For instance, should it appear that there are in this country any considerable number of deaf-mutes who are themselves the offspring of deaf-mutes the indications are that a large proportion of these persons will marry, and that of those who marry, the majority will marry deaf-mutes. Thus, there is every indication that in the case of the deaf and dumb the work of selection will go on from generation to generation.

# Chapter III.

## DEAF-MUTE OFFSPRING OF DEAF-MUTE MARRIAGES.

In a paper upon "Hereditary Deafness"* (published in 1868), Rev. W. W. Turner, then principal of the American Asylum, said that "statistics, carefully collated from records kept of deaf-mutes as they have met in conventions at Hartford, show that *in 86 families with one parent a congenital deaf-mute, one-tenth of the children were deaf; and in 21 families with both parents congenital deaf-mutes, about one-third were born deaf.*

In support of this conclusion he presented the following table:

Table XXIV.

| Class. | Parents. | Number of families. | Number of children deaf. | Number of children hearing. | Total. |
|---|---|---|---|---|---|
| 1 | One hearing and 1 congenitally deaf .......... | 30 | 15 | 77 | 92 |
| 2 | One incidentally and 1 congenitally deaf ..... | 56 | 6 | 120 | 126 |
| 3 | Both congenitally deaf ...................... | 21 | 17 | 40 | 57 |
| | Total ................................ | 110 | 38 | 237 | 275 |

Dr. Turner cited in connection with his subject the case of one woman who lived to see great grandchildren, and of these no less than sixteen were deaf-mutes.

Regarding intermarriage, he said: "It is a well-known fact that among domestic animals certain unusual variations of form or color which sometimes occur among their offspring, may, by a careful selection of others similar and by a continued breeding of like with like, be rendered permanent, so as to constitute a distinct variety. The same course adopted and pursued in the human race would undoubtedly lead to the same result." He concluded with the remark, "that every consideration of philanthropy as well as the interests of congenitally deaf persons themselves should induce their teachers and friends to urge upon them the impropriety of intermarriage."

It is reasonable to suppose that, whatever influence Dr. Turner's statements may have exerted upon the marriages of the deaf throughout the country, his conclusions and beliefs must have had considerable weight with the pupils of his own institution, and this may perhaps have been the cause of the decrease in the proportion of intermarriages noted among the pupils of his institution since the date of his paper. (See Table XXIII.)

In the report of the New York Institution, published in the American Annals of the Deaf and Dumb, July, 1854 (vol. vi, pp. 193 to 241), Dr. Harvey L. Peet gave the following table, showing the number of pupils of the New York Institution married, as compared with the married pupils of other American institutions, and compared with the marriages of the deaf in Europe, no distinction being made between those who were congenitally deaf and those who became deaf from accidental causes.

* See Proceedings National Conference of Principals of Institutions for the Deaf and Dumb, Washington, D. C., 1868; see, also, American Annals for the Deaf and Dumb, 1868, Vol. XIII, pp. 244-246; also article "Deaf and Dumb" Encyclopædia Britannica.

Dr. Peet stated that of all the families embraced in the table "*about one in twenty have deaf-mute children where both parents are deaf-mutes, and about one in one hundred and thirty-five where only one is a deaf mute; and that the brothers and sisters of a deaf mute are about as liable to have deaf-mute children as the deaf-mute himself, supposing each to marry into families that have or or each into families that have not shown a predisposition toward deaf-dumbness.*"

TABLE XXV.

| Name of institution. | Married hearing persons. | | Married deaf-mutes. | |
|---|---|---|---|---|
| | *Males.* | *Females.* | *Males.* | *Females.* |
| Pupils of the New York Institution* | 19 | 29 | 66 | 77 |
| Pupils of the Hartford Asylum* | 43 | 25 | 104 | 89 |
| Pupils of the Ohio Asylum | 13 | 1 | 18 | 21 |
| Pupils of the Gronningen Institution (Holland) | 28 | 8 | 6 | 6 |
| City of Paris | 14 | 1 | 15 | 15 |
| Belgium (census of 1835) | 7 | ........ | 1 | 1 |
| Ireland (census of 1851) | 45 | 32 | 5 | 5 |
| Yorkshire Institution (England) | 1 | 2 | ........ | ........ |
| Leipsic Institution (Germany) | 4 | 1 | ........ | ........ |
| Prague Institution (Bohemia) | 6 | ........ | 2 | 2 |
| Luxemburg Institution (Netherlands) | 2 | ........ | ........ | ........ |
| Lyons Institution (France) | 2 | ........ | ........ | ........ |
| Geneva Institution (Switzerland) | 1 | ........ | ........ | ........ |
| Russia Institution (incidental notices) | 2 | ........ | 1 | 1 |
| Bavaria Institution (incidental notices) | 1 | ........ | ........ | ........ |
| Total | 188 | 106 | 218 | 217 |
| Deduct the three American institutions | 75 | 58 | 188 | 187 |
| Remains for Europe | 113 | 48 | 30 | 30 |

*Some marriages have been deducted from the Hartford list that appear also in the New York list. There have also been marriages between educated and uneducated mutes, or between deaf-mutes of our schools and semi-mutes not pupils.

From this table it appears that *at the time of the investigation (1851) marriages of deaf-mutes and especially between two deaf mutes, were far more common in America than in Europe; and that, except among the pupils of the New York Institution, there were twice as many deaf-mute men with hearing wives, as deaf-mute women with hearing husbands.*

Principals of institutions for the deaf and dumb have personal knowledge of their pupils, and may therefore be able to arrive at correct conclusions regarding the results of intermarriage.

It is extremely difficult, if not impossible, for others to arrive at an independent conclusion from the data published in the institution reports. It is even impossible to ascertain from these reports the mere number of the deaf offspring recorded as born to the pupils. The nature of the difficulty will be understood by an example. From the 1877 report of the American Asylum we find that—

George W. A—— (born about 1803) "married a deaf-mute" and had 3 deaf children.

Mary R—— (born about 1808) "married a deaf-mute" and had 3 deaf children.

Jonathan M—— (born about 1814) "married a deaf-mute" and had 3 deaf children.

Paulina B—— (born about 1817) "married a deaf-mute" and had 3 deaf children.

Now the query presents itself, "how many deaf children were born to these pupils?" Perhaps Mary R—— was the wife of George W. A——, and Paulina B—— the wife of Jonathan M——, in which case there are only 6 deaf children in all. It is possible, however, that in such cases the males and females were not related in marriage, and upon this supposition there were 12 deaf children.

There is generally nothing in the institution reports to guide us to a solution of the problem. If the names of the husbands and wives of the pupils were recorded it would be possible to arrive at some conclusion. As it is, the most we can do is to ascertain the number of deaf children recorded as the offspring of the male pupils and those noted as born to the female pupils. Even though it were possible to arrive at a correct conclusion regarding the total number of deaf offspring recorded in the reports, still we would not be able to ascertain the actual number of deaf children born to the pupils. For it is obvious, from the following considerations, that the number recorded is so much less than the number born as to lead to the inference that in a considerable proportion of cases the deaf offspring are not recorded at all until some of the children make their appearance in the institution as pupils. This means that they may not be recorded until 10, 20, or even 25 years after the date of their birth. I may be wrong in such a supposition, but I do not know how otherwise to account for the imperfection of the records:

(1) In the 1877 report of the American Asylum the married male pupils were recorded to have had 36 deaf children born to them and the married female pupils 28. Whereas 57 children of deaf-mute marriages have already been admitted into the institution as pupils (November, 1883*), all of whom were born before the 1877 report was issued. This does not include a number of deaf-mutes who have been admitted into other institutions in New England whose parents were pupils of the American Asylum, nor does it include children too young to be sent from home.

(2) In the 1882 report of the Illinois Institution the married male pupils were recorded to have had 10 deaf children born to them and the married female pupils 8. Whereas 14 children have already been admitted into the Illinois Institution (November, 1883†) one or both of whose parents were deaf.

(3) A comparison of the four reports of the American Asylum containing the statistics of the institution shows that only a small proportion of the deaf offspring of the *later marriages* are recorded in the 1877 report. This will be obvious from the following table:

TABLE XXVI.—*Congenitally deaf pupils who married deaf-mutes.*

| Presumed date of marriage.* | Number of males married. | Recorded number of deaf children born to the males. | Number of females married. | Recorded number of deaf children born to the females. |
|---|---|---|---|---|
| Before 1843 | 18 | 4 | 17 | 11 |
| Between 1843 and 1857 | 42 | 13 | 46 | 5 |
| Between 1857 and 1867 | 22 | .. | 30 | 1 |
| Between 1867 and 1877 | 38 | .. | 26 | .. |

Deduced from a comparison of the four reports of the American Asylum. (See Introduction to Table XXIII.)

From this table it appears that 116 congenital deaf-mutes (males and females) have married deaf-mutes since the 1857 report was issued and that only *one* deaf child resulted from these marriages (!). This is most extraordinary, in view of the results obtained by Dr. Turner, which were based upon the marriages of the pupils of the same institution, and we must conclude that the records of the later marriages are defective so far as the deaf offspring are concerned.

An examination of the tables in the appendix shows that of all the pupils of the American Asylum and Illinois Institution 445 males and 371 females are recorded to have married. In the 445 families formed by the males there were (according to the reports) 46 deaf children, or 10.3 deaf children for every 100 families; and in the 371 families formed by the females there were 36 deaf children, or 9.7 in 100 families.

* Reported to the writer by Mr. Williams, the present principal of the institution.
† Reported to the writer by Dr. Gillett, the present principal of Illinois Institution.

If we add together the total number of males and females reported to have married and the total number of deaf children stated to have been born to them, we obtain the following figures: 816 individuals married, and 82 deaf offspring. We cannot conclude from this that the records indicate that 82 deaf children were born to the 816 pupils referred to, for many of the male pupils mentioned had undoubtedly married female deaf-mutes educated in the same institution with themselves. In such cases the deaf offspring were probably recorded twice—once under the name of the father and once under the name of the mother. If we desire to obtain, not the actual number of deaf children recorded to have been born to the pupils, but the *proportionate number*, we may safely add together the children recorded to have been born to the male and female pupils; for, if 816 families have 82 deaf children, the proportionate number of deaf children (10 for every 100 families) is a mean between the results obtained from the marriages of the males and females considered separately, and is more reliable than either from being based on larger numbers. In the following tables this plan of addition has been adopted, and it must be remembered that the number of families noted and the number of deaf children born, as deduced from the reports of the American Asylum and Illinois Institution, must not be taken to indicate the *actual* number of families formed by the pupils of these institutions, nor the *actual* number of deaf children born to them. They simply indicate a proportion, which is expressed in the third column by a percentage.

If none of the males married females recorded in the same reports, then the figures in the following tables would indicate *actual* as well as proportionate numbers; but this is not the case.

TABLE XXVII.—*Proportion of deaf offspring resulting from the marriages of deaf-mutes.*

[Deduced from the reports of the American Asylum and Illinois Institution.]

| Married couples. | Number of families. | Number of deaf children. | Percentage (number of deaf children to every 100 families). |
|---|---|---|---|
| Both parties deaf-mutes | 654 | 66 | 10.1 |
| One party a deaf-mute | 162 | 16 | 9.9 |
| One or both parties deaf-mutes | 816 | 82 | 10.0 |

The following tables enable us to compare the above results with those obtained from each institution, considered separately:

TABLE XXVIII.—*Proportion of deaf offspring as deduced from reports of Illinois Institution and American Asylum.*

ILLINOIS INSTITUTION.

| Married couples. | Number of families. | Number of deaf children. | Percentage (number of deaf children to every 100 families). |
|---|---|---|---|
| Both parties deaf-mutes | 152 | 17 | 11.2 |
| One party a deaf-mute | 22 | 1 | 4.5 |
| One or both parties deaf-mutes | 174 | 18 | 10.3 |

AMERICAN ASYLUM.

| | | | |
|---|---|---|---|
| Both parties deaf-mutes | 502 | 49 | 9.8 |
| One party a deaf-mute | 140 | 15 | 10.1 |
| One or both parties deaf-mutes | 642 | 64 | 10.0 |

The percentages obtained indicate, of course, the number of deaf children for every 100 families *as recorded in the reports*, and not the actual number of deaf children for every 100 families (which is known to be greater).

The general results obtained from the two institution reports are remarkably concordant.

In the case of the American Asylum, however, it appears that the pupils who married hearing persons had a larger proportion of deaf children than those who married deaf-mutes(!) Such a remarkable result requires explanation. The pupils assumed to have married hearing persons are simply recorded in the report as "married," but from private correspondence with the present principal (Mr. Williams) I find that in most, if not in all, cases so recorded the record is really intended to indicate marriage with a hearing person.

Even in the case of the congenitally deaf pupils of the American Asylum it appears that those who married hearing persons had a larger proportion of deaf offspring than those who married deaf-mutes. The following table shows that this result can be deduced not only from the tables in the appendix, but from the table quoted above from Dr. Turner's paper on Hereditary Deafness:

TABLE XXIX.

| Class. | Marriages of the congenitally deaf. | Dr. Turner's results (1868) for pupils of the American Asylum. | | | Results from 1877 report of American Asylum. | | |
|---|---|---|---|---|---|---|---|
| | | Number of families. | Number of deaf children. | Percentage (number of deaf children for every 100 families). | Number of families. | Number of deaf children. | Percentage (number of deaf children for every 100 families). |
| 1 | One parent congenitally deaf and the other a hearing person | 30 | 15 | 50.0 | 57 | 14 | 24.6 |
| 2 | Both parents deaf-mutes (one congenitally deaf and the other incidentally deaf) | 56 | 6 | 10.7 | (?) | (?) | (?) |
| 3 | Both parents deaf-mutes (both congenitally deaf) | 24 | 17 | 70.9 | (?) | (?) | (?) |
| 4* | Both parents deaf-mutes (one or both congenitally deaf) | 80 | 23 | 28.7 | 239 | 34 | 14.2 |

* Class 4 gives summation of classes 2 and 3.

I have already stated that in the majority of the cases that have fallen under my personal observation where a deaf-mute was married to a hearing person that *the hearing person belonged to a family containing deaf-mutes*, and this is significant in the light of the results deduced above, especially when we remember that the late Dr. Harvey L. Peet found that "the brothers and sisters of a deaf mute are about as liable to have deaf mute children as the deaf-mute himself, supposing each to marry into families that have or each into families that have not shown a predisposition toward deaf-dumbness." If we examine the cases of the pupils who are presumed to have married hearing persons in the light of this idea, separating the sporadic cases from those who have deaf-mute relations, we obtain the following results:

We find from the tables in the appendix that 162 deaf-mutes were "married," presumably, to hearing persons. Of these deaf-mutes 55 are stated to have had deaf-mute relatives, and they are recorded to have had 15 deaf children, or more than 27 deaf children for every 100 families; on the other hand, 107 of these deaf mutes were noted as sporadic cases, and only one deaf child is recorded as the offspring of the marriages!

We have here a clear indication that *a hereditary tendency towards deafness, as indicated by the possession of deaf relatives, is a most important element in determining the production of deaf offspring. The following table shows that it may even be a more important element than the mere fact of congenital deafness in one or both of the parents.*

TABLE XXX.—*Deaf-mute offspring of deaf-mute marriages.*

[Results deduced from the tables in the appendix, combining the figures obtained from the reports of the American Asylum and Illinois Institution.]

| Description of married couples. | Number of families. | Number of deaf children. | Percentage* (number of deaf children to every 100 families). |
|---|---|---|---|
| (1) Father known to be a deaf-mute (summation of all cases where the cause of father's deafness is stated): | | | |
| (*a*) Father recorded to be congenitally deaf | 187 | 25 | 13.3 |
| (*b*) Father recorded to be non-congenitally deaf | 237 | 18 | 7.6 |
| (2) Mother known to be a deaf-mute (summation of all cases where the cause of mother's deafness is stated): | | | |
| (*a*) Mother recorded to be congenitally deaf | 173 | 31 | 17.9 |
| (*b*) Mother recorded to be non congenitally deaf | 179 | 4 | 2.9 |
| (3) Father known to be a deaf-mute (summation of all such cases): | | | |
| (*a*) Father known to have deaf-mute relatives | 132 | 23 | 17.4 |
| (*b*) Father recorded as a sporadic case | 313 | 23 | 7.3 |
| (4) Mother known to be a deaf-mute (summation of all such cases): | | | |
| (*a*) Mother known to have deaf-mute relatives | 153 | 25 | 16.3 |
| (*b*) Mother recorded as a sporadic case | 218 | 11 | 5.0 |
| (5) One parent known to be a deaf-mute (summation of all cases where the cause of deafness was stated): | | | |
| (*a*) Deaf-mute parent recorded to be congenitally deaf | 360 | 56 | 15.5 |
| (*b*) Deaf-mute parent recorded to be non-congenitally deaf | 416 | 22 | 5.3 |
| (6) One parent known to be a deaf-mute (summation of all cases): | | | |
| (*a*) Deaf-mute parent known to have deaf-mute relatives | 285 | 48 | 16.8 |
| (*b*) Deaf-mute parent recorded as a sporadic case | 531 | 34 | 6.4 |
| (7) One parent recorded to be congenitally deaf (summation of all cases): | | | |
| (*a*) Congenitally deaf parent known to have deaf-mute relatives | 230 | 41 | 17.8 |
| (*b*) Congenitally deaf parent recorded as a sporadic case | 130 | 15 | 11.5 |
| (8) One parent recorded to be non-congenitally deaf (summation of all cases): | | | |
| (*a*) Non-congenitally deaf parent known to have deaf-mute relatives | 53 | 5 | 9.4 |
| (*b*) Non-congenitally deaf parent recorded as a sporadic case | 363 | 17 | 4.7 |
| (9) Both parents known to be deaf-mutes (summation of all cases): | | | |
| (*a*) One parent known to have deaf-mute relatives | 230 | 33 | 14.7 |
| (*b*) One parent recorded as a sporadic case | 424 | 33 | 7.8 |
| (10) Both parents known to be deaf-mutes and one recorded as congenitally deaf: | | | |
| (*a*) Congenitally deaf parent known to have deaf-mute relatives | 186 | 27 | 14.5 |
| (*b*) Congenitally deaf parent recorded as a sporadic case | 112 | 15 | 13.4 |
| (11) Both parents known to be deaf-mutes, and one recorded as non-congenitally deaf: | | | |
| (*a*) Non-congenitally deaf parent known to have deaf-mute relatives | 43 | 4 | 9.3 |
| (*b*) Non-congenitally deaf parent recorded as a sporadic case | 288 | 16 | 5.5 |
| (12) One parent known to be a deaf-mute and the other presumed to be a hearing person (summation of all cases): | | | |
| (*a*) The deaf-mute parent known to have deaf-mute relatives | 55 | 15 | 27.3 |
| (*b*) The deaf-mute parent recorded as a sporadic case | 107 | 1 | 0.9 |
| (13) One parent recorded to be a congenital deaf-mute, the other presumed to be a hearing person: | | | |
| (*a*) Congenitally deaf parent known to have deaf-mute relatives | 44 | 14 | 31.8 |
| (*b*) Congenitally deaf parent recorded as a sporadic case | 18 | None. | (?) |
| (14) One parent recorded to be a non-congenital deaf-mute, the other presumed to be a hearing person: | | | |
| (*a*) Non-congenital deaf-mute parent known to have deaf-mute relatives | 10 | 1 | 10.0 |
| (*b*) Non-congenital deaf-mute parent recorded as a sporadic case | 75 | 1 | 1.3 |
| (15) General results (summation of all cases of marriage recorded): | | | |
| Average | 816 | 82 | 10.0 |

*The percentages are given as deduced from the institution reports. The true percentages are probably much greater, but *proportionally greater.*

(*a*) The large proportion of deaf offspring resulting from marriages where the father was known to have deaf-mute relatives, and from those where the mother was known to have deaf-mute relatives, and the comparatively small proportion where either parent appeared to be free from hereditary taint, seem to point to the conclusion that *in a large proportion of cases in which the marriages were productive of deaf offspring both parents had deaf-mute relatives (even in the case where one parent was a hearing person).*

(*b*) A similar process of reasoning leads to the conclusion that *in a large proportion of marriages where deaf offspring resulted both parents were probably congenitally deaf where both were deaf-mutes, and one parent congenitally deaf where only one was a deaf-mute.*

(*c*) It is thus highly probable that *a large proportion of the deaf offspring of deaf-mute marriages had parents who were both congenitally deaf, and who also both had deaf-mute relatives.*

(*d*) *Non-congenital deafness, if sporadic, seems little likely to be inherited.*

(*e*) Another deduction we may make is that *more of the deaf offspring whose parents had deaf relatives will marry than of those whose parents were recorded as sporadic cases, for there are more of them; and they will have a greater tendency than the others to transmit their defect to the grandchildren.*

These results are in close accordance with the experience of the venerable principal of the Pennsylvania Institution, as expressed in the following letter:

PENNSYLVANIA INSTITUTION FOR DEAF AND DUMB,
*Philadelphia, November* 14, 1883.

A. GRAHAM BELL, Esq.:

DEAR SIR: Continued ill health has prevented an earlier compliance with your request of October 15. The list I now send is full and accurate, according to the records of the institution and my recollection. In regard to most of the cases, I know of no place where fuller information can be obtained than our books furnish.

A residence of more than forty years in this institution has afforded me abundant opportunity for observation in regard to the subject of your research. A statement of the conclusions I have arrived at may be of some interest and use to you.

In regard to the marriage of deaf mutes with each other, if both the man and the woman are deaf from birth, there is very great danger—I should say a strong probability—that some of the offspring will be born deaf. I know a family, however, where the mother is one of three congenitally deaf children and the father one of five, and the seven children they have had are all without defect. In the list sent you all the parents, except in two cases, were born deaf. In one of these two cases the father could hear; in the other the mother is a semi-mute.

Where both parents became deaf adventitiously, there seems to be no more probability of the offspring being born deaf than there is where both parents hear.

Where only one of the parents is congenitally deaf, the children almost always hear.

Any further information I can give will be furnished willingly.

Yours, respectfully,

JOSHUA FOSTER.

My attempts to deduce from the records of the marriages of the deaf the influences that cause the production of deaf offspring have met with only partial success. Valuable indications have been obtained, but precise and accurate results are unattainable, on account of imperfect data. It occurred to me some time ago that a different method might lead to an exhaustive examination of the subject. It is known that few of the deaf and dumb married before the establishment of educational institutions in this country, and nearly 78 per cent. of all the marriages recorded in the reports of the American Asylum (the oldest institution in the country), seem to have been contracted since the year 1843. The probabilities are, therefore, that the vast majority of the deaf offspring born *are still living*, and from them may be obtained an accurate account of their ancestry. It also appeared probable that the majority of these deaf-mutes would at some period of their lives, make their appearance in institutions for the deaf and dumb, and from the institution records might be obtained their names and addresses. Such considerations as the above led me to send to all the institutions in the country a circular letter of inquiry requesting the names and addresses of all the pupils who had been admitted who had deaf-mute parents, and returns have been received from a number of institutions.*

A starting point has thus been gained for a new investigation of the subject. The cases returned are sufficient in number to throw some light upon the proportion of deaf offspring born to deaf mutes as compared with the proportion born to the community at large. The total number of deaf-mutes in the country, according to the recent census, is 33,878, which gives us a proportion of one deaf mute for every 1,500 of the population. If, then, the proportion of deaf mutes, originating among the deaf mutes themselves, were no greater than in the community at large, they should constitute only 1 in 1,500 of the deaf-mute population. In other words, we should not have more than 23 deaf-mutes in the United States who are themselves the children of deaf mutes. The returns received from the institutions, however, show that no less than 215 such children *have already been admitted as pupils* into 35 of the 58 institutions of the country (23 institutions not replying to my queries). Pupils are rarely admitted before they are 10 or 12 years of age and many do not reach the institution until they are much older. Hence it is evident that this number does not at all express the total number of such cases in the United States. Even if we suppose that no more than 230 such cases are to be found in the country, the proportion is ten times greater than in the community at large, or 1 in 150. But when we consider that nearly all of these children were born deaf, whereas nearly half of the deaf mutes of the country (45.9 per cent.) became deaf from accidental causes, we realize that the liability to the production of *congenital deaf-mutes* is more nearly *twenty* times that of the population at large than ten times. It is evident that whatever may be the actual number of deaf-mutes in the country who have one or both parents deaf, the true number is much greater than that assumed above. From which it follows that the liability to the production of deaf offspring is also greater. While, then, we cannot at present arrive at any percentage, it is certain that *the proportion of deaf-mute offspring born to deaf-mutes is many times greater than the proportion born to the people at large.*

* See Tables S, T, U, and W of the Appendix. My best thanks are due to the principals and superintendents for their assistance in this investigation.

# Chapter IV.

## FAMILIES OF DEAF-MUTES.

The reports of the American Asylum, New York, Ohio, Indiana, and Illinois Institutions show that in each institution deaf-mutes have been received who belong to families containing five, six, or even more deaf-mutes; and there is abundance of evidence to indicate that such families are very numerous in the United States. In cases where there are five or six children of one family deaf and dumb some of them marry when they grow up, and in many cases they marry persons who belong, like themselves, to families containing several deaf-mutes. Thus it happens that we have here and there, scattered over the country, *groups of deaf-mute families* connected together by blood and marriage.

The probability is very strong that the deaf-mute children of deaf-mute marriages will at some time or other make their appearance in the educational institutions of the country, and we might reasonably hope to be able to trace the family relations from the published reports of the institutions. Unfortunately, in the majority of cases, the information that can be gleaned in this way is very fragmentary and uncertain, for the names of the husbands and wives of the pupils are rarely quoted, so that it is impossible in the great majority of cases to trace the connections. A female deaf-mute, when she marries, changes her name to that of her husband; the new name is not recorded in the institution reports, and we lose track of her branch of the family. Should she have deaf offspring they make their appearance in the institution under another family name, and the connection is not obvious. So far as my researches have gone they indicate the probability of a connection by blood or marriage between many of the largest of the deaf-mute families of the New England States.

In the following diagram (Fig. 1) I exhibit the results of an attempt to trace the connections of the Brown family, of Henniker, N. H., in which there are known to be at least four generations of deaf-mutes.

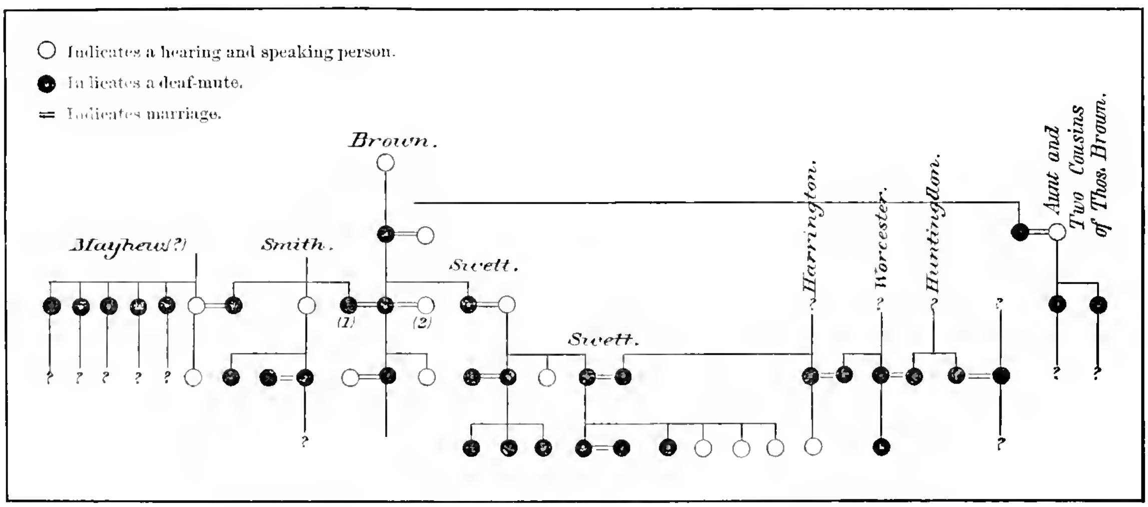



Fig. 1.—The Brown family of Henniker, N. H., and a few of its connections.

*The Brown family, of Henniker, N. H.*—The ancestor of this family was one of the early pioneers of New Hampshire. He left Stowe, in Massachusetts, somewhere about the year 1787, and settled in Henniker, N. H.

His deaf-mute son Nahum (born in 1772) married a hearing lady, by whom he had a son and daughter, both deaf and dumb. His son Thomas, when he entered the American Asylum as a pupil, was recorded to have had "an aunt and two cousins deaf and dumb." (This branch of the family has not yet been certainly identified.) Thomas married a deaf-mute (Mary Smith, of Chilmark, Mass.), by whom he had two children, Thomas L. (a deaf-mute) and a hearing daughter who died young. The son Thomas L. married a hearing lady (Almira G. Harte, of Burlington, Vt.), and removed to Michigan, where he became one of the teachers of the Michigan Institution for the Deaf and Dumb. I have no information concerning his descendants.

The deaf-mute daughter of Nahum married a hearing gentleman, Mr. Bela M. Swett, of Henniker, N. H., by whom she had three sons (Thomas B., William B., and Nahum). The eldest son, Thomas, was born deaf; the second son, William, was born deaf in one ear, and lost the hearing of the other in childhood from measles; and the third son, Nahum, could hear. The eldest son, Thomas, married a deaf-mute, and his three children (Mitchell, Charlotte E., and Mary S.) are deaf-mutes. The second son, William, married a deaf-mute (Margaret Harrington) by whom he had five children, all of whom could hear at birth, but two of them (Persis H. and Lucy Maria) lost their hearing so early in life as to necessitate their education in institutions for the deaf and dumb. Two others died young and one has retained her hearing into adult life. The eldest daughter (Persis, born 1852) has married a deaf-mute. It will thus be seen that three families of deaf-mutes have sprung from Nahum Brown, and in two of these the deafness has descended to the fourth generation. In the other family it descended to the third generation, beyond which I have been unable to trace the family. The deaf-mute connections of the Brown family have only been partially worked out.

1. The wife of William B. Swett was Margaret Harrington, who had a deaf-mute brother, Patrick, who married a deaf-mute (Sarah Worcester), who had a twin deaf-mute brother (Frank), who married a deaf-mute (Almira Huntington), who had a deaf-mute sister (Sophia M.), who married a deaf-mute (James R. Hines).* Frank Worcester, one of the twin deaf-mutes has a deaf-mute son—the other twin (Susan) has a child who hears.

2. On the other side of the family, the wife of Thomas Brown (Mary Smith, of Chilmark, Martha's Vineyard) had a hearing brother (Capt. Austin Smith), who had two deaf-mute children (a son and a daughter). The son (Freeman N.) married a deaf-mute (Deidama West).† Mrs. Brown also had a deaf-mute sister (Sally), who "married a hearing man of Martha's Vineyard (Hariff Mayhew) who had 5 deaf-mute brothers and sisters."

*The Lovejoy family.*—This is another New England family in which deafness has been handed down through four generations. Benjamin Lovejoy, a deaf-mute, of Sidney, Me., is recorded in

* The father and mother of James R. Hines (Isaac and Sophia) were both deaf-mutes, and he has a deaf-mute son (Eddie), and a cousin deaf and dumb. His mother (Sophia Rowley) also has a deaf-mute cousin.

† They had a deaf-mute daughter (Lovina). Deidama West had a deaf-mute mother, Deidama (Tilton) West, and two maternal uncles deaf and dumb (Franklin and Zeno Tilton) who married deaf-mutes. She also had three brothers and one sister deaf and dumb (George, Benjamin, Joseph L., and Rebecca). George married a deaf-mute (Sabrina Rogers), and has a deaf-mute child (Eva S. West). Benjamin married a hearing lady (Mary Hathaway). I have no information concerning their offspring. Rebecca married a deaf-mute (Eugene Trask), who had a deaf-mute brother (John Trask) who married a deaf-mute. George Trask, a deaf-mute, born about 1880, is probably the son of Eugene Trask and Rebecca West.

the reports of the American Asylum to have had "a grandfather, father, and 3 children deaf and dumb." There are other families of deaf-mutes of the same name which are obviously connected. (See Fig. 7.)

*The Ouat family, of Illinois.*—Two members of this family entered the Illinois Institution in 1859 and 1862. It was recorded of them in the 1882 report that there had been deafness in the family for five generations. No particulars, however, are given.

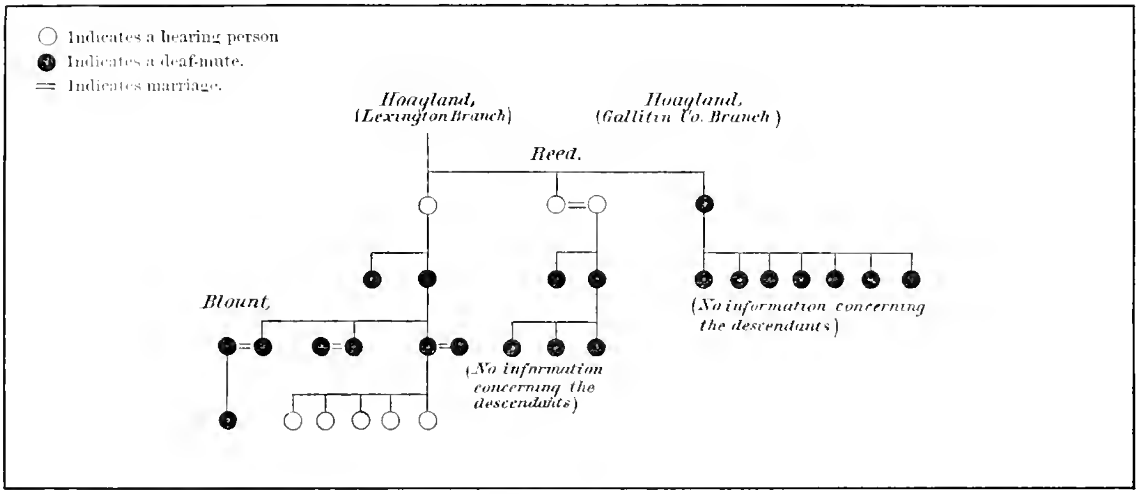



FIG. 2.—The Hoagland family of Kentucky.

*The Hoagland family, of Kentucky* (Fig. 2.)—This is one of the most remarkable of the deaf-mute families of America. In the above diagram I have attempted to show the family connections so far as they are known to me. In 1853 this family was stated to consist of a father, himself deaf and dumb, with 7 deaf-mute children. He had 2 deaf-mute nephews, one of whom was married and had two deaf-mute children. He also had a hearing sister who had two deaf-mute sons, one of whom had 3 children, all deaf-mutes.*

The principal of the Kentucky Institution has kindly furnished me with the following additional particulars concerning this family. He says:

"In 1822 two brothers, Thomas and William Hoagland, entered our institution. Thomas never married, but William married a deaf mute. He had a son and two daughters, all of whom were mutes and married mutes. Jesse, the son, has five children, all of whom can hear. Mrs. Blount, the eldest daughter, has one son, a mute; Clara, the other daughter, is childless. This may be called the Lexington branch, as their home was there. Another, the Gallatin County branch, contained seven deaf-mutes. In another branch, the Reeds, the father and his three children are mutes. Only a part of all these mutes have been at school, and it is difficult to trace n the scanty records the exact relationship between the different branches."

*The Adkins family, of Kentucky.*—This family was stated in 1853 to contain nine deaf-mutes.†

*The Grisson family, of Kentucky.*—I am indebted to the principal of the Kentucky Institution for the following very instructive particulars concerning this family:

"There were three or four deaf-mute brothers and sisters of this family who were pupils here (Kentucky Institution) about the year 1828; one of them, William, married a deaf-mute lady and

* American Annals of the Deaf and Dumb, vol. vi, p. 255.

† American Annals of the Deaf and Dumb, vol. vi, p. 256.

had a numerous family, all of whom could hear. One of his sons married his cousin, also a hearing person, *and all of their five children are deaf mutes.*"

In 1870 Mr. Benjamin Talbot, then principal of the Iowa Institution, published in the American Annals of the Deaf and Dumb (vol. xv, p. 118) an account of some families of deaf-mutes residing in his State. One or two of the most remarkable cases may be noted which are of a particularly suggestive character.

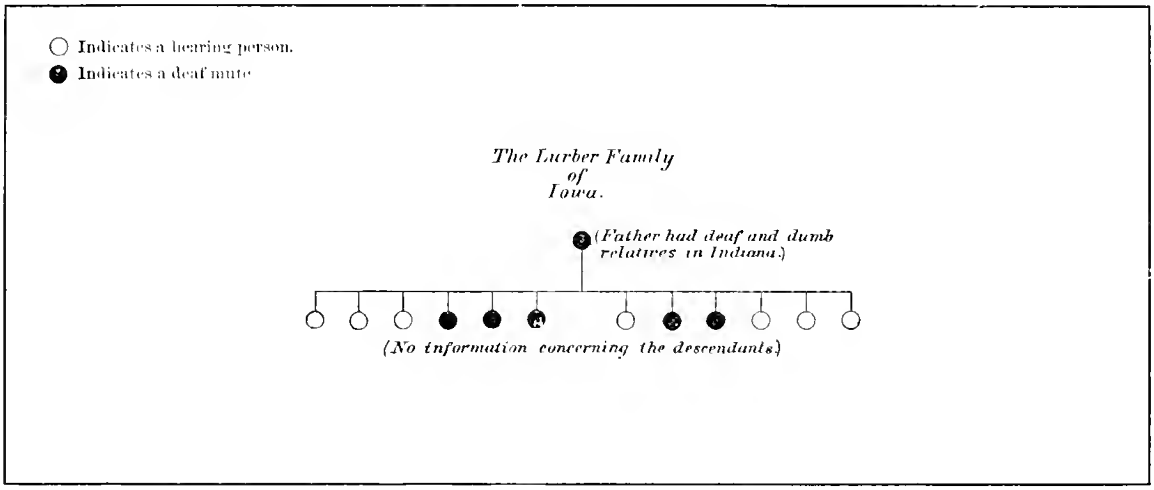



FIG. 3.—The Lurber family of Iowa.

*The Lurber family, of Iowa* (Fig. 3).—"The father is a deaf-mute, without education, who came to Iowa from Indiana, where there are, or have been, several deaf-mute relatives. Of twelve children in this family only one, and she the eighth, was born deaf. Four others, the fourth, fifth, sixth, and ninth, have lost their hearing in whole or in part, and have been sent to school here (Iowa Institution)."

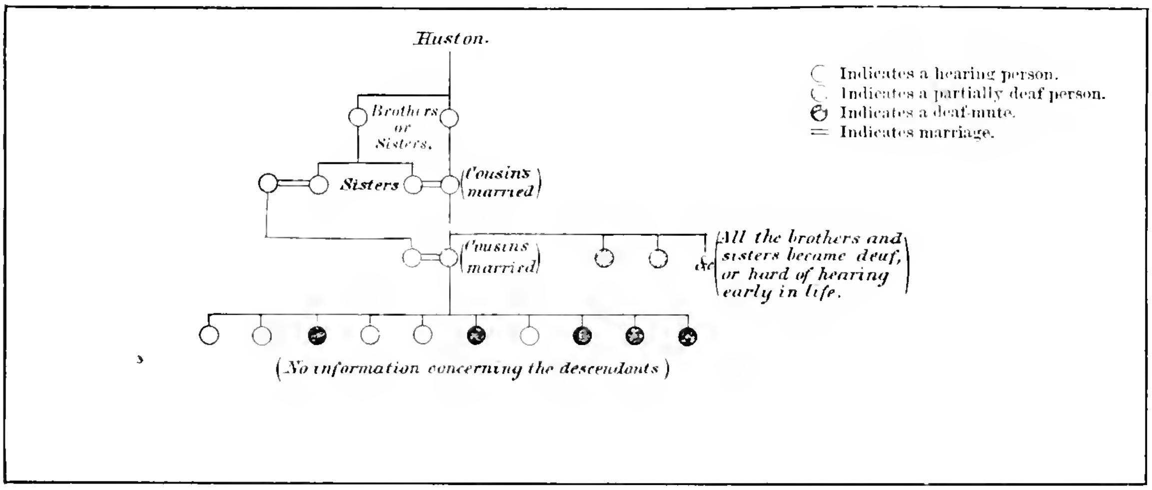



FIG. 4.—The Huston family of Iowa.

*The Huston family, of Iowa* (Fig. 4).—"There have been ten children in this family, of whom the third and eighth lost their hearing by disease, while the sixth, ninth, and tenth were born deaf.

Mr. Huston's grandmothers were sisters, and the grandfather and grandmother of this family were first cousins. Mr. Huston's brothers, like himself, were healthy and long lived, but, like him, *they all became deaf*, or at least hard of hearing, comparatively early in life."

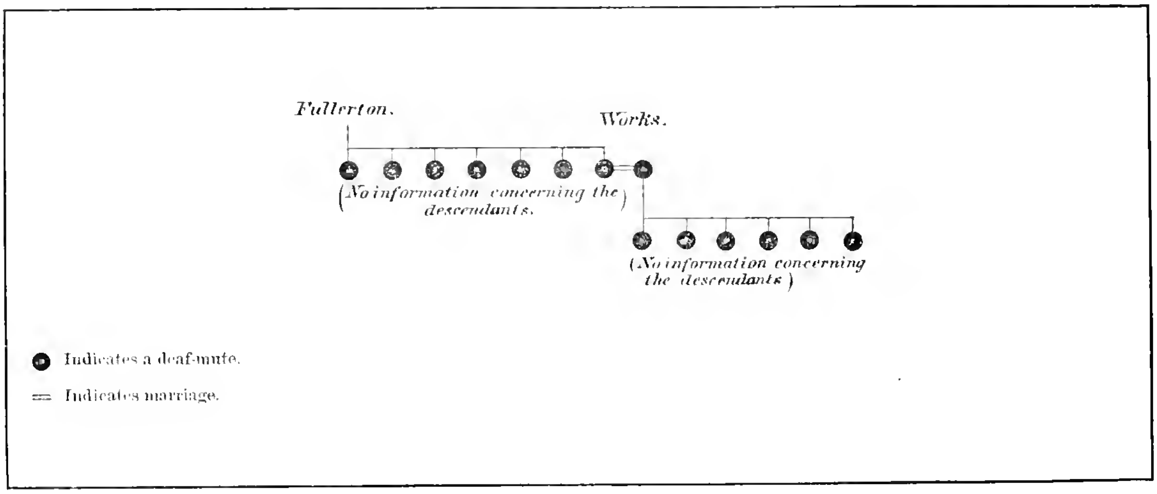



FIG. 5.—The Fullerton family of Hebron, N. Y.

*The Fullerton family, of Hebron, N. Y.* (Fig. 5).—Sayles Works, born 1806 (a presumed congenital deaf-mute of the New York Institution), married Jane Fullerton, born 1806 (a congenital deaf-mute educated in the same institution), who had six brothers and sisters deaf and dumb. All of their six children were deaf and dumb. There were thus fourteen deaf-mutes in this family. I have no information concerning the descendants.

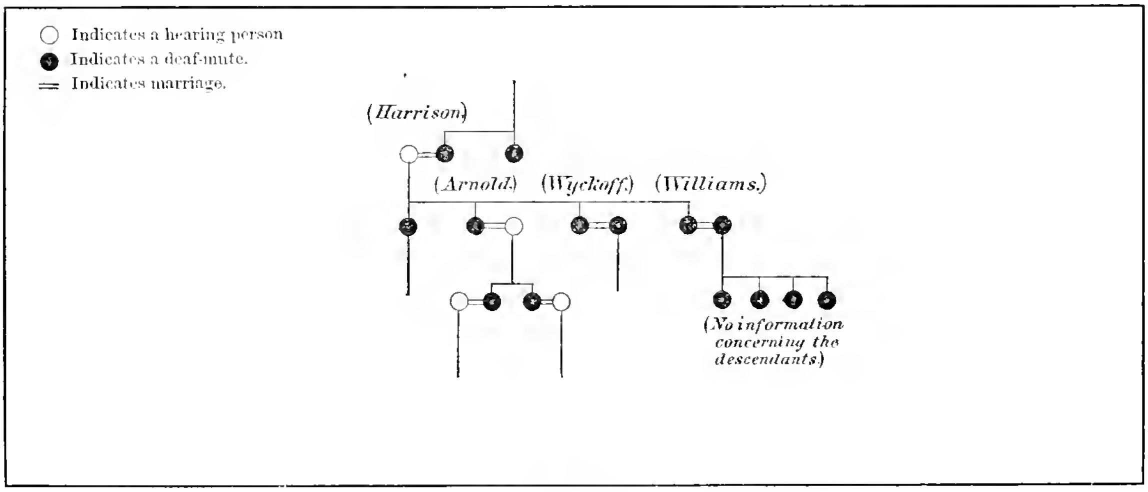



FIG. 6.—A family indicated in the 1854 report of the New York institution.

*A remarkable family reported from the New York Institution for the Deaf and Dumb.*—The particulars of this family, as gleaned from the 1854 report of the New York Institution, are shown in the above diagram (Fig. 6): As the descent is in the female line, this genealogical table could not have been made had it not been for the fact that the New York report gives the names of the husbands and wives of some of the pupils.

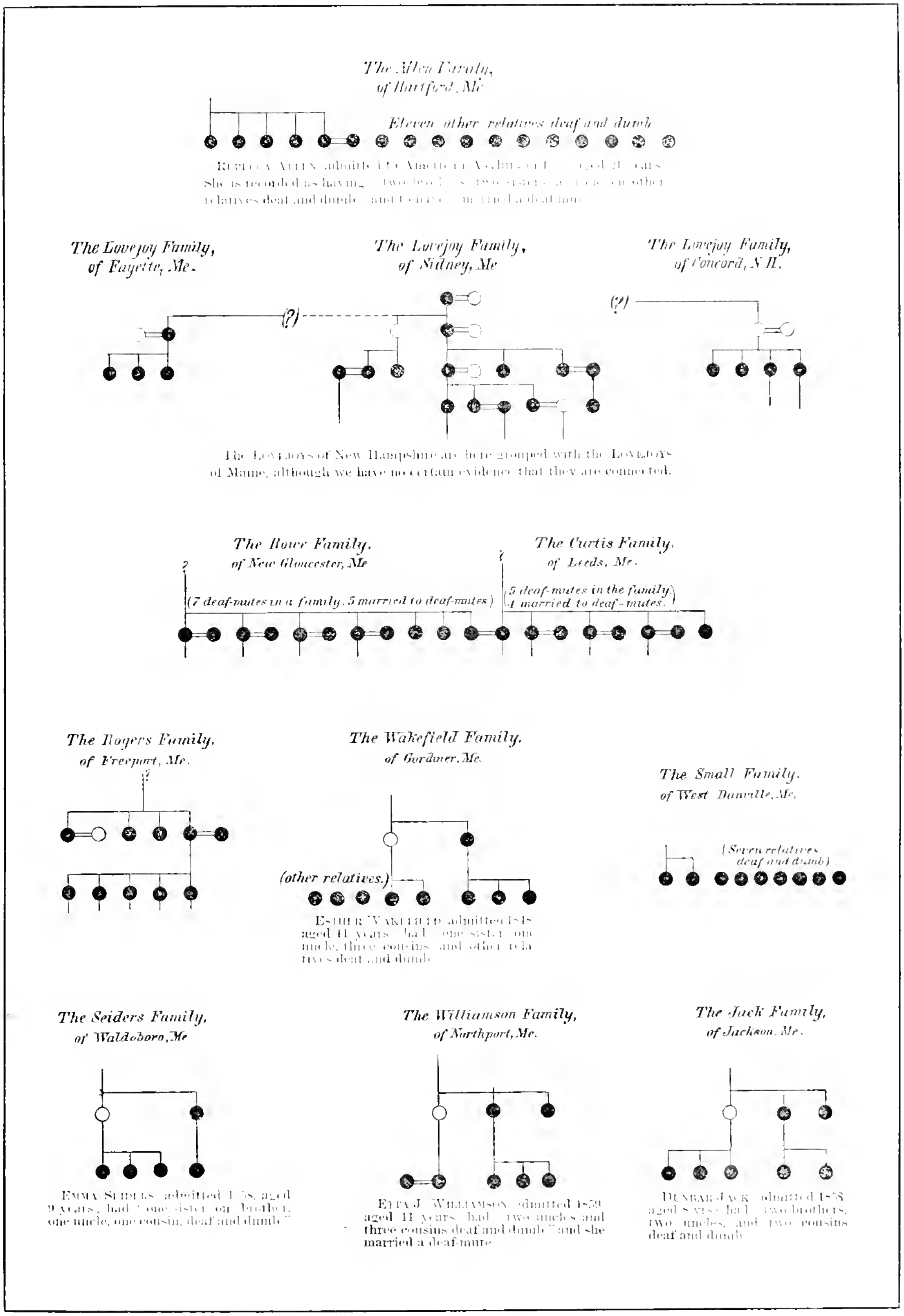



FIG. 7.—A group of deaf-mute families from Maine.

*A group of deaf-mute families from Maine.*—Members of the deaf-mute families shown in Fig. 7 have been admitted into the American Asylum at Hartford, Conn. There is no record showing any relationship between the families, but their close proximity to one another is extremely suggestive. The fact that there are four generations of deaf mutes in the Lovejoy family suggests the idea that some of the other families may perhaps be descended from it through the female line. Whatever the explanation, it is at all events remarkable that so many large deaf-mute families should have originated in small places within a few miles of one another.

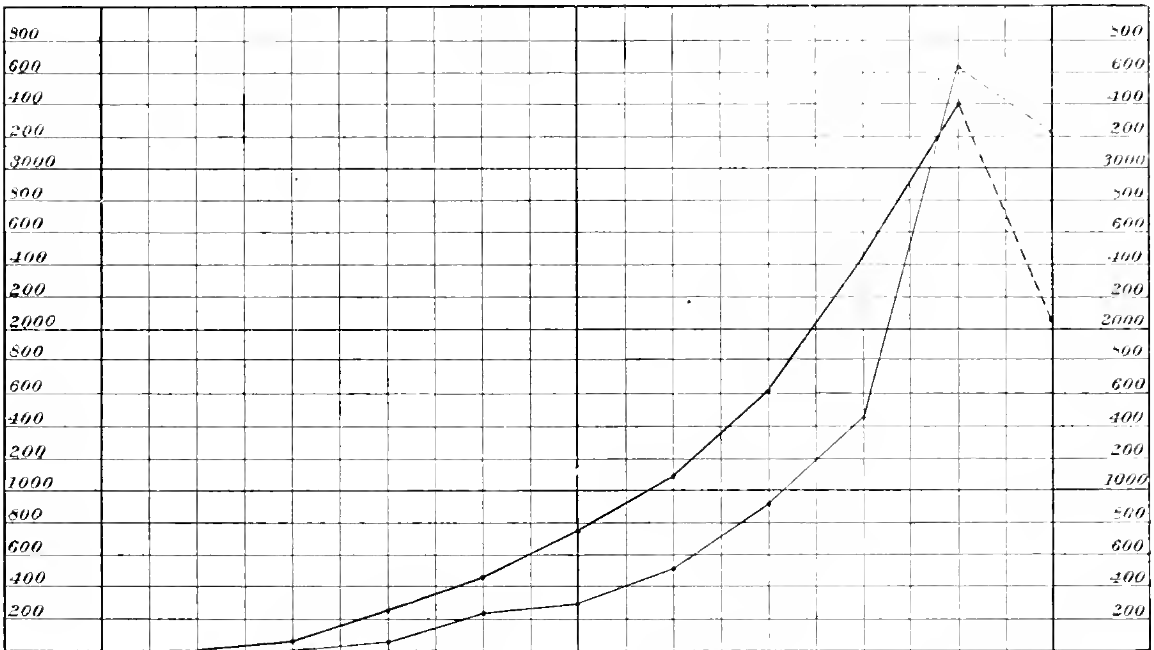
It must not be supposed that I have attempted to give an exhaustive list of the large deaf-mute families. I have simply given specimen cases to prove that in many different parts of the country deafness has been transmitted by heredity. There are many more large families known to me which are not alluded to above.

# CHAPTER V.

## UPON THE GROWTH OF THE DEAF-MUTE POPULATION.

The full returns of the 1880 census, so far as regards the deaf and dumb, have not yet been published; but, as stated before, Rev. Frederick H. Wines, who had charge of this department of the census, presented to the tenth convention of American instructors of the deaf and dumb the results of an analysis of 22,472 cases of deaf-mutes reported in the census returns. The tables presented by Mr. Wines have been reproduced in the Appendix. (See Tables N, O, P, Q.)

It will be observed that the cases are classified according to the period when deafness occurred and according to the cause of deafness (whether congenital or not). I have rearranged these cases into decades, so as to correspond with the classification of the pupils of the American Asylum and Illinois Institution, and have represented the results graphically in the following diagram:



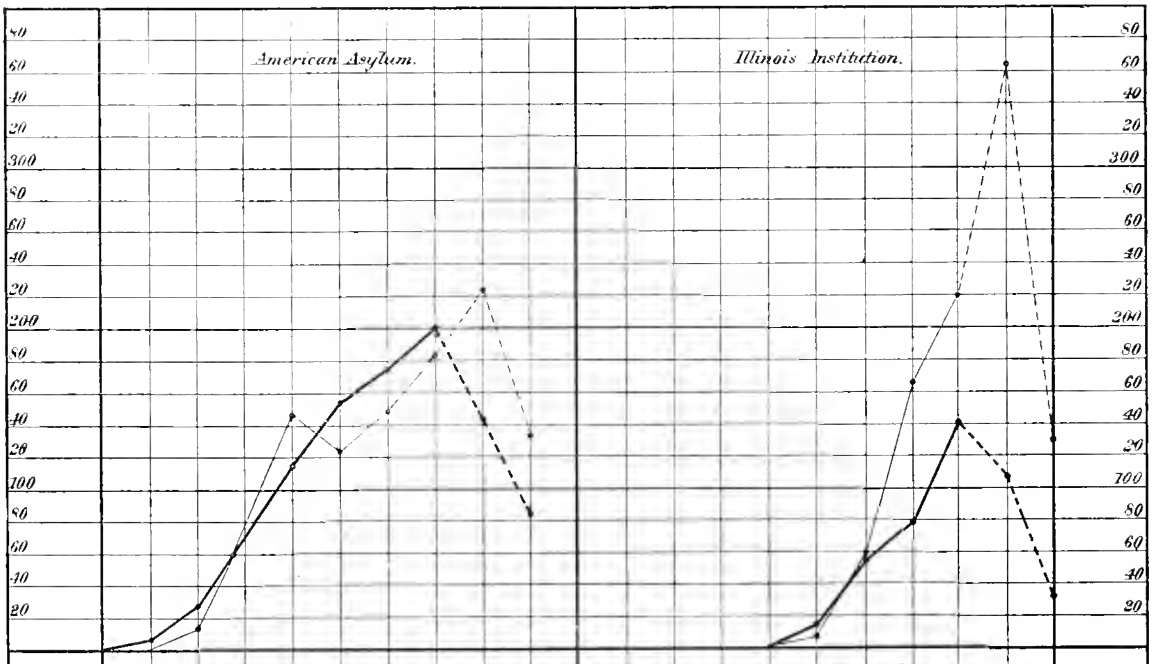

| Period. | 1781–1790 | 1791–1800 | 1801–1810 | 1811–1820 | 1821–1830 | 1831–1840 | 1841–1850 | 1851–1860 | 1861–1870 | 1871–1880 |
|---|---|---|---|---|---|---|---|---|---|---|
| Congenital deaf-mutes. | 9 | 63 | 241 | 472 | 751 | 1078 | 1614 | 2460 | 3390 | 2068 |
| Non-Congenital deaf-mutes. | 1 | 8 | 53 | 227 | 307 | 514 | 895 | 1454 | 3620 | 3240 |

FIG. 8.—Relation between the congenital and non-congenital deaf-mutes of the country, according to the Rev. Fred. H. Wines. The congenital deaf-mutes are indicated by the dark line; the non-congenital, by the light line.

The ordinates of the curves represent, respectively, the number of congenital and non-congenital deaf-mutes who became deaf in the decades indicated by the abscissæ. In the case of the congenital deaf-mutes the ordinates also represent the number who were born in the decades given, but this is not true of the non-congenitals. It will be observed that the number of deaf-mutes returned who became deaf in the last decade, 1871–'80, is less than the number who became deaf in the preceding decade. This does not necessarily mean that the number actually was less, but more probably indicates that the returns for the last decade are imperfect. Mr. Wines says that "In proportion to the degree of their youth the younger deaf-mutes are not enumerated. Fewer deaf-mutes who are babes in arms are enumerated than at the age of three years, and fewer at three years than at seven. The apparent maximum at seven is not the actual maximum; the actual maximum is at some younger age not yet ascertained."

In the above diagram those portions of the curves that are believed to be unreliable from this cause are indicated by dotted lines.

It will be observed that among the older deaf mutes the congenitals are more numerous than the non-congenitals; whereas among the younger the reverse appears to be the case. There is no apparent diminution in the numbers of the congenitally deaf born of late years; and the reversal of the relation between the two classes must be attributed to an abnormal increase in the number of those who became deaf from disease or accident. It looks as if a wave of deafness-producing disease had swept over the continent about the time of the late civil war.




| Period of birth. | 1780–1789 | 1790–1799 | 1800–1809 | 1810–1819 | 1820–1829 | 1830–1839 | 1840–1849 | 1850–1859 | 1860–1869 | 1870–1879 | 1780–1789 | 1790–1799 | 1800–1809 | 1810–1819 | 1820–1829 | 1830–1839 | 1840–1849 | 1850–1859 | 1860–1869 | 1870–1879 | Period of birth. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Congenital deaf-mutes. | 6 | 27 | 73 | 114 | 153 | 173 | 198 | 144 | 83 | — | — | — | — | 1 | 13 | 52 | 77 | 140 | 105 | 29 | Congenital deaf-mutes. |
| Non-congenital deaf-mutes. | 1 | 12 | 70 | 147 | 124 | 146 | 182 | 224 | 133 | — | — | — | — | 2 | 11 | 58 | 164 | 217 | 364 | 129 | Non-congenital deaf-mutes. |

FIG. 9.—The dark lines indicate those pupils who were born deaf, and the light lines those who became deaf from disease or accident.

There are indications also of a similar though less disturbance in the numbers of those who lost their hearing from disease during the decade 1811 to 1820. An examination of the reports of the American Asylum and Illinois institution may throw light upon the nature of these disturbances. By classifying the pupils of these institutions according to their period of birth, we obtain the results that are exhibited graphically in the foregoing diagram (Fig. 9).

The apparent decrease in the number of pupils born in the last two decades is susceptible of simple explanation. Very few pupils are received into institutions for the deaf and dumb before they are ten or twelve years of age, while it is not uncommon for pupils to be admitted at twenty or twenty-five years of age or even older.

A pupil born in the year 1869 would only be 13 years of age in 1882 (the date of the Illinois report). It is evident, therefore, that of those deaf mutes who were born in the decade 1860 to 1869 who will ultimately make their appearance in the Illinois institution all had not been received at the date of the report.

A similar explanation can be given in the case of the American Asylum. The dotted lines indicate those portions of the curves which are known to be inaccurate on this account.

In regard to the American Asylum the abnormal increase in the number of pupils who became deaf from disease or accident who were born during the decade 1810–'19 is very marked. Another abnormal increase is observable in the number of those who became deaf in the decade 1860–'69. Indeed, the relations of the congenital and non-congenital deaf-mutes are reversed in a similar manner to that shown in Fig. 8. In regard to the Illinois pupils (see Fig. 9) it will be observed that the increase in the numbers of the non-congenitally deaf is so enormous, that of the pupils who were born in the decade 1860–'69 there were more than three times as many non-congenitally deaf as there were congenitally deaf, and of those born in 1870–'79 more than four times, whereas the census returns show that more than half of all the deaf-mutes living in this country (1880) were born deaf.

In the reports of the American Asylum and Illinois institutions the year when each pupil was admitted and his age when admitted are noted, with few exceptions. From these elements the period of birth has been calculated. The period when hearing was lost has also been ascertained in all cases where the age of the pupil when deafness occurred is stated in the report.

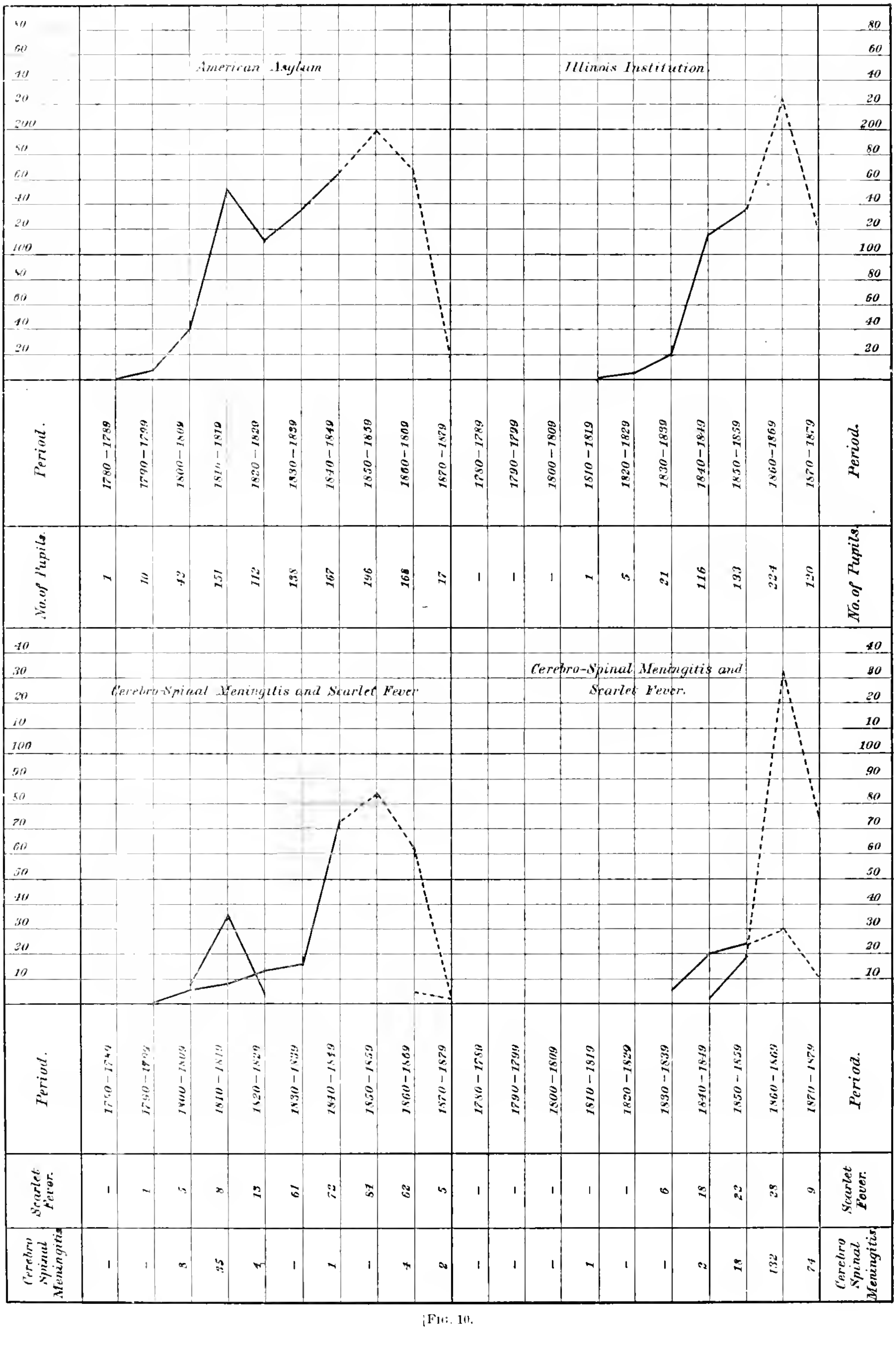
In tables K and L of the Appendix the non-congenital pupils of both institutions are classified according to the period when hearing was lost and according to the disease that caused deafness. In regard to the Illinois report it is unfortunately the case that the age of the pupil when deafness occurred is not stated in 327 cases out of 947, so that we are only able to classify about two-thirds of the cases in this way. The results are shown graphically in the upper diagrams of Fig. 10.

From the tables in the Appendix we have clear evidences of two epidemics of "spotted fever,"* or epidemic cerebro-spinal meningitis. One epidemic during the decade 1810 to 1819, reaching a maximum in the year 1815, and the other (a great epidemic) in the decade 1860 to 1869, continuing in the last decade, 1870 to 1879.

The pupils who became deaf from cerebro-spinal meningitis and from scarlet fever are classified according to the period when deafness occurred in the lower diagrams of Fig. 10.

*The numbers of the non-congenitally deaf are evidently subject to great and sudden fluctuations on account of epidemical diseases which cause deafness, whereas the growth of the congenitally-deaf population seems to be much more regular.*

*According to Dr. Russell Reynolds "spotted fever" is a popular name for epidemic cerebro-spinal meningitis. See "A System of Medicine," 1880, Vol. I, pp. 296–7.

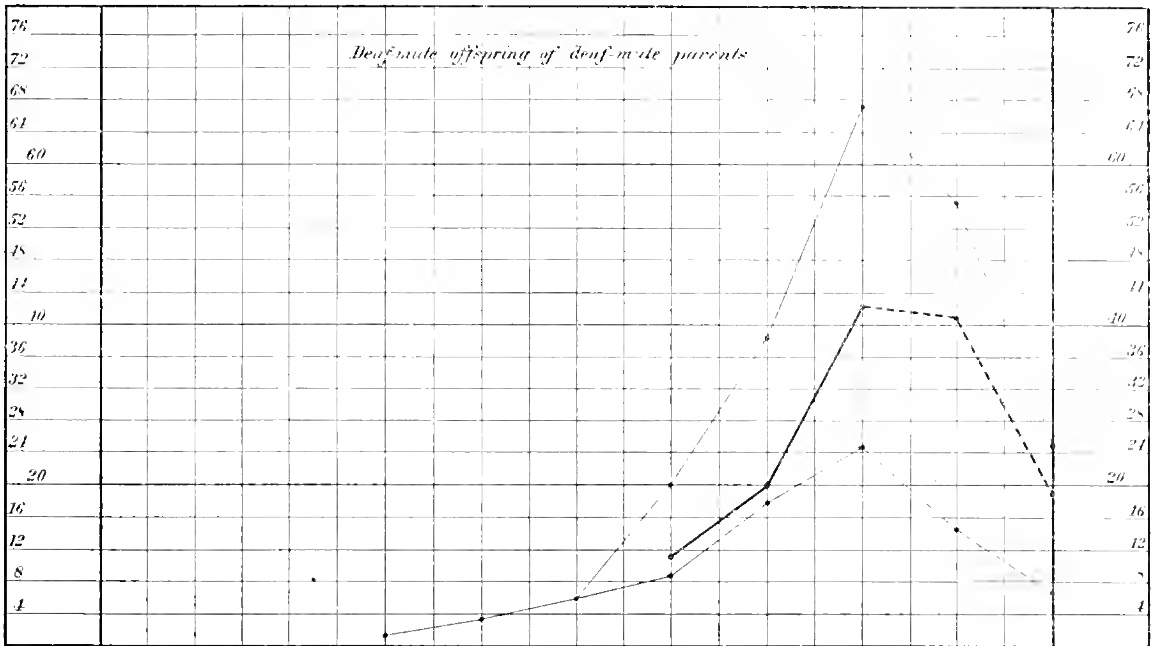



| Period. | 1780–1789 | 1790–1799 | 1800–1809 | 1810–1819 | 1820–1829 | 1830–1839 | 1840–1849 | 1850–1859 | 1860–1869 | 1870–1879 | 1780–1789 | 1790–1799 | 1800–1809 | 1810–1819 | 1820–1829 | 1830–1839 | 1840–1849 | 1850–1859 | 1860–1869 | 1870–1879 | Period. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. of Pupils. | 1 | 10 | 42 | 151 | 112 | 138 | 167 | 196 | 168 | 17 | – | – | – | 1 | 5 | 21 | 116 | 133 | 224 | 120 | No. of Pupils. |

| Period. | 1780–1789 | 1790–1799 | 1800–1809 | 1810–1819 | 1820–1829 | 1830–1839 | 1840–1849 | 1850–1859 | 1860–1869 | 1870–1879 | 1780–1789 | 1790–1799 | 1800–1809 | 1810–1819 | 1820–1829 | 1830–1839 | 1840–1849 | 1850–1859 | 1860–1869 | 1870–1879 | Period. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Scarlet Fever. | – | 1 | 5 | 8 | 13 | 61 | 72 | 81 | 62 | 5 | – | – | – | – | – | 6 | 18 | 22 | 28 | 9 | Scarlet Fever. |
| Cerebro Spinal Meningitis | – | – | 8 | 35 | 4 | – | 1 | – | 4 | 2 | – | – | – | 1 | – | – | 2 | 18 | 132 | 74 | Cerebro Spinal Meningitis |

FIG. 10.

In Table T of the Appendix I have classified 215 cases of deaf-mutes who are the offspring of deaf-mutes according to their period of birth, separating those who have one parent deaf from those who have both. The results are shown graphically in Fig. 11.




| Period of birth. | 1781–1790 | 1791–1800 | 1801–1810 | 1811–1820 | 1821–1830 | 1831–1840 | 1841–1850 | 1851–1860 | 1861–1870 | 1871–1880 | Period of birth. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total. | — | — | 1 | 3 | 6 | 20 | 38 | 67 | 55 | 25 | Total. |
| Nº having both parents deaf. | — | — | — | — | — | 11 | 20 | 42 | 41 | 19 | Nº having both parents deaf. |
| Nº having one parent deaf. | — | — | 1 | 3 | 6 | 9 | 18 | 25 | 14 | 6 | Nº having one parent deaf. |

FIG. 11.—The dark line indicates the deaf-mutes who have both parents deaf. The lower light line represents those who have one parent deaf, and the upper line the total number of deaf-mutes returned who have one or both parents deaf.

No deaf-mute having both parents deaf has been returned who was born before the year 1832. It seems probable, therefore, that the oldest deaf-mute in the country whose parents were both deaf-mutes is only now a little past middle age. We have therefore received into our institutions only *the first generation* of deaf-mutes born from the intermarriage of deaf-mutes. The apparent decrease in the number born since 1861 does not necessarily indicate a real decrease, for many of the deaf-mutes born in the decade 1861 to 1870 have not yet been admitted to institutions for the deaf and dumb. Those portions of the curves that we know to be unreliable from this cause are represented in dotted lines.

In concluding this portion of my subject it may be well to institute a comparison between the deaf-mute population and the total population of the country as returned by the census of 1880.

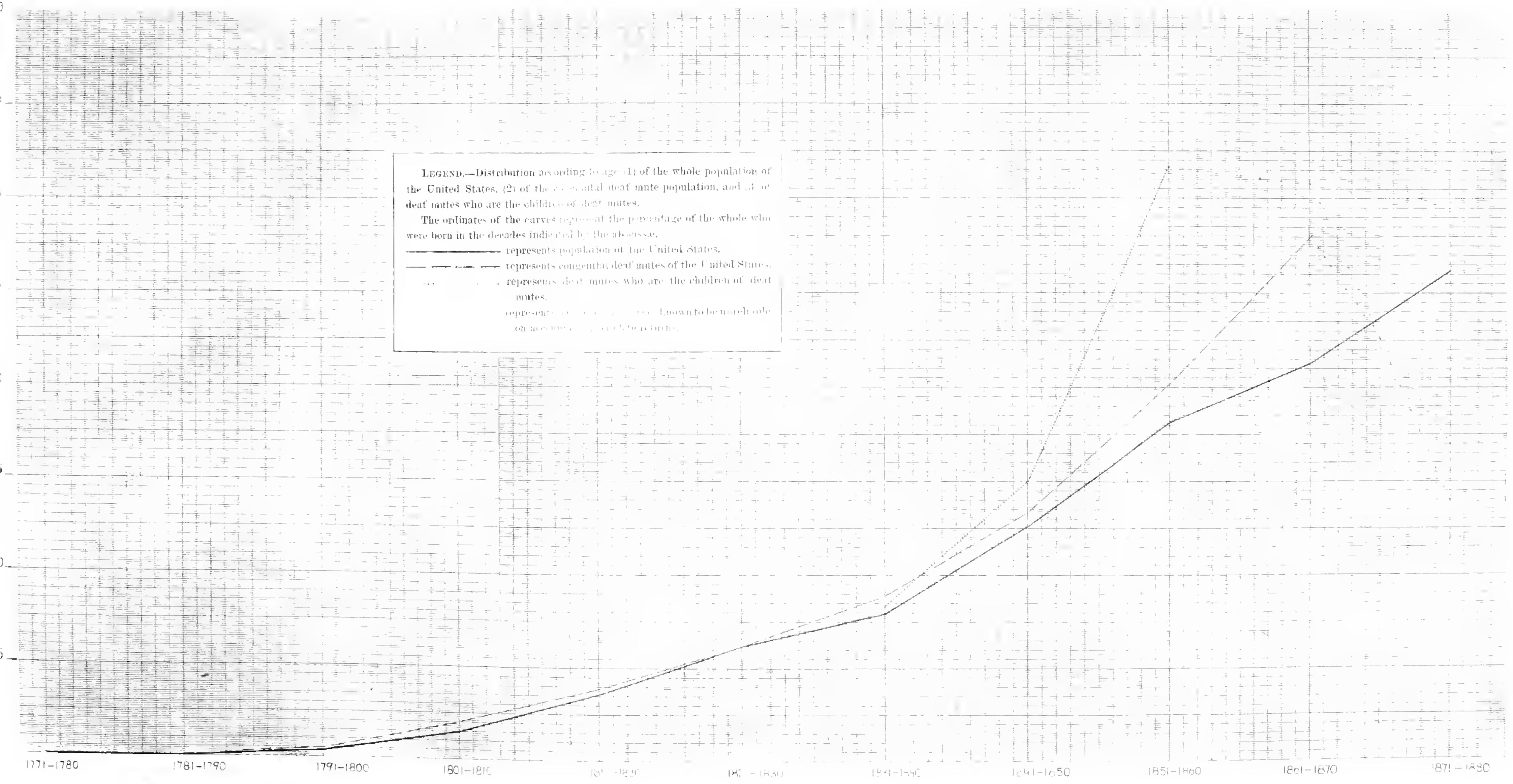
In Table II of the Appendix I have classified the people of the United States according to the decades in which they were born, and have reduced the number born in each decade to a percentage of the whole. In the same table I have classified the 12,154 congenital deaf-mutes mentioned by Mr. Wines in a similar manner, and also the deaf-mutes who have both parents deaf-mutes. We can thus examine upon the same scale the distribution of the three classes according to age. The results are shown graphically in the diagram, Fig. 12.

The ordinates represent the percentage of the whole who were born in the decades indicated by the abscissæ.

If we assume that the numerical relation now existing between congenital deaf-mutes and hearing persons *of the same age* approximately represents the proportion of the congenitally deaf to the whole population born at the period when they were born, we have a means of comparing the growth of the congenitally deaf population with that of the population at large.

*The indications are that the congenital deaf-mutes of the country are increasing at a greater rate than the population at large; and the deaf-mute children of deaf-mutes at a greater rate than the congenital deaf-mute population.*

Fig. 12.



Legend.—Distribution
of the whole population of
the United States, (2) of the
deaf mute population, and
deaf mutes who are the
mutes.
The ordinates of the curves
the whole who
were born in the decades
represents
represents
deaf mutes of the
represents
the children of
mutes.
1771–1780
1781–1790
1791–1800
1801–1810
1841–1850
1851–1860
1861–1870
1871–1880

# Chapter VI.

## UPON THE CAUSES THAT DETERMINE THE SELECTION OF THE DEAF BY THE DEAF IN MARRIAGE.

In the preceding chapters I have shown that sexual selection is at work among the deaf and dumb, tending to produce a deaf variety of the human race.

Those who believe as I do, that the production of a defective race of human beings would be a great calamity to the world, will examine carefully the causes that lead to the intermarriages of the deaf with the object of applying a remedy.

It is a significant fact that "before the deaf and dumb were educated comparatively few of them married";* and intermarriage (if it existed at all) was so rare as to be practically unknown. This suggests the thought that the intermarriages of the deaf and dumb have in some way been promoted by our methods of education. When we examine the subject from this point of view a startling condition of affairs becomes apparent.

Indeed, if we desired to create a deaf variety of the race, and were to attempt to devise methods which should compel deaf-mutes to marry deaf-mutes, we could not invent more complete or more efficient methods than those that actually exist and which have arisen from entirely different and far higher motives.

Let us, then, consider how we might proceed to form a race of deaf-mutes, if we desired so to do, and let us compare the steps of the process with those that have been adopted by philanthropists and others, from the purest and most disinterested motives, to ameliorate the condition of the deaf and dumb. How would we commence?

1. With such an object in view, would it not be of importance to separate deaf-mutes from hearing persons as early in life as possible and make them live together in the same place, carefully guarding them from the possibility of making acquaintances among hearing persons of their own age? This is what we do. We take deaf children away from their homes and place them in institutions by the hundred, keeping them there from early childhood to the commencement of adult life.

2. It would also be of importance to promote social intercourse among them in adult life, so that the boys and girls of former years should meet again as men and women. We might, for instance, hold periodical reunions of former pupils at the institutions. This again is what we do.

Indeed, the graduates of our institutions now commonly organize themselves into societies or associations for the promotion of social intercourse in adult life. Societies of deaf-mutes are to be found in all large cities, and in many of the smaller ones. Rooms are hired in a central locality, which become the rendezvous of the deaf-mutes of the neighborhood. After the business of the day is done the deaf-mutes of the city meet together for social intercourse, and on Sundays for public worship. Not only do local societies exist, but there are State associations for promoting social intercourse between the deaf-mutes of a State. Periodical conventions are held in different

*See "The Causes of Deafness," by the Rev. W. W. Turner, American Annals of the Deaf and Dumb, Vol. 1, p. 32.

parts of the State, attended by deaf-mutes of both sexes. At these meetings they amuse themselves in various ways. Sometimes they hold fairs—have theatrical representations in dumb show, spectacular tableaux, dancing, &c.

Not only do these State associations exist, but a National Association has been formed for the purpose of promoting social intercourse between the scattered deaf-mutes of the country. The Second National Convention of Deaf Mutes met only a short time ago in New York and was attended by hundreds of deaf-mutes from all parts of the United States.

3. Another method calculated to foster class-feeling among the deaf and dumb would be to provide them with newspapers and periodicals of their own, which should make a specialty of "personals" relating to the deaf and dumb—newspapers that should give full accounts of the deaf-mute conventions and reunions, and keep their readers informed of the movements of deaf-mutes, their marriages, deaths, &c. Quite a number of such newspapers have come into existence.* The majority being supported by the educational institutions of the country, with the benevolent object of teaching the deaf-mutes the art of printing. These papers, I understand, are generally edited and printed in the institutions, under the superintendence of the teachers. It was only natural to include among the items "personals" concerning former pupils, and that former pupils of the institution should take pleasure in reading them. In addition to the periodicals printed in the institutions, others have appeared edited and managed by adult deaf-mutes not connected with any institution. These latter papers became the organs of communication between the adult deaf-mutes, and were affiliated with the conventions and associations above referred to.

4. The methods specified above, while they serve to facilitate social intercourse between adult deaf-mutes, do not necessarily prevent them from also associating with hearing persons. As there are 1,500 hearing persons for every one deaf-mute, it seems difficult to formulate any plan which would restrict their choice of partners in life to deaf-mutes alone or to the hearing members of deaf-mute families. Let us consider how this could be accomplished.

What more powerful or efficient means could be found than to teach the deaf-mutes to think in a different language from that of the people at large? This is what we do. In the majority of our institutions for the deaf and dumb a special language is used as the vehicle of thought, a language as different from English as French or German or Russian. The English language is confined to the school-room and is simply taught as a school exercise, much as French and German are taught in the public schools.

The deaf-mutes *think* in the gesture language, and English is apt to remain a foreign tongue. They can communicate with hearing persons by writing, but they often write in broken English as a foreigner would speak. They think in gestures and often translate into written English with the idioms of the sign language. The constant practice of the sign language interferes with the mastery of the English language, and it is to be feared that comparatively few of the congenitally deaf are able to read books understandingly unless couched in simple language. They are thus in a great measure cut off from our literature. This is another element in forcing them into each other's society. They are able to understand a good deal of what they see in our daily newspapers, especially if it concerns what interests them personally, but the political speeches of the day, the leading editorials, &c., are often beyond their knowledge of the English language.

*These must not be confounded with the American Annals of the Deaf and Dumb, a journal of a very different character, not intended to be read specially by deaf-mutes themselves. This journal is a quarterly magazine devoted to the discussion of subjects connected with the education of the deaf and dumb, and forms the official organ of communication between teachers. It is one of the most admirably conducted special journals in existence, and contains within its pages almost the complete literature of the world relating to the education of the deaf and dumb.

5. Another method of consolidating the deaf and dumb into a distinct class in the community would be to reduce the sign-language to writing, so that the deaf-mutes would have a common literature distinct from the rest of the world. Such a species of writing would constitute a form of ideography like the Egyptian hieroglyphics. This, I understand, has already been accomplished by the late Mr. George Hutton, of Ireland, afterwards principal of the Institution for the Deaf and Dumb in Halifax, Nova Scotia.* The full publication of his method was prevented by his premature death; but a committee was appointed by the Indianapolis Convention of American Instructors of the Deaf and Dumb, to act in conjunction with his successor and son, Mr. J. Scott Hutton, to attempt the recovery of the system from the posthumous papers of Mr. George Hutton. I have not yet seen the report of the committee.

6. Another and very powerful method of obstructing intercourse with hearing persons and compelling deaf-mutes to associate exclusively with one another would be to disseminate throughout the community incorrect ideas concerning the deaf and dumb, so that people should avoid and even fear them. The growth of erroneous ideas is favored by collecting deaf-mutes into institutions away from public observation. People rarely see a deaf-mute, and their information concerning them is chiefly derived from books and periodicals.

Whatever the cause, it is certainly the case that adult deaf-mutes are sometimes hampered by the instinctive prejudices of hearing persons with whom they desire to have business or social relations. Many persons have the idea they are dangerous, morose, ill-tempered, &c. Then again people do not understand the mental condition of a person who cannot speak and who thinks in gestures. He is sometimes looked upon as a sort of monstrosity, to be stared at and *avoided*. His gesticulations excite surprise and even sometimes alarm in ignorant minds. In connection with this subject I may say that as lately as 1857 a deaf-mute was shot dead in Alabama by a man who was alarmed by his gestures.† In fact fallacies concerning the deaf and dumb are so common as *to touch us all* and to suggest the advisability of seriously examining the fundamental ideas we hold concerning them.

I have elsewhere discussed the subject of "Fallacies concerning the deaf and the influence of these fallacies in preventing the amelioration of their condition," and shall not therefore enlarge upon the subject here. I shall simply give a few of the conclusions at which I arrived in the paper referred to.‡

"1. Those whom we term 'deaf-mutes' have no other natural defect than that of deafness. They are simply persons who are deaf from childhood, and many of them are only 'hard of hearing.'

"2. Deaf children are dumb not on account of lack of hearing, but of lack of instruction. No one teaches them to speak.

"3. A gesture-language is developed by a deaf child at home, not because it is the only form of language that is natural to one in his condition, but because his parents and friends neglect to use the English language in his presence in a clearly visible form.

"4. (*a*) The sign-language of our institutions is an artificial and conventional language derived from pantomime.

"(*b*) So far from being natural either to deaf or hearing persons, it is not understood by deaf children on their entrance to an institution. Nor do hearing persons become sufficiently familiar

* See Mr. Hutton's article "Upon the Practicability and Advantages of Mimography," American Annals of the Deaf and Dumb, vol. xiv, pp. 157–182.

† See American Annals of the Deaf and Dumb, Vol. x, p. 116.

‡ See Bulletin Philosophical Society of Washington, D. C., October 27, 1883; also American Annals of the Deaf and Dumb, January, 1884.

with the language to be thoroughly qualified as teachers until after one or more years' residence in an institution for the deaf and dumb.

"(c) The practice of the sign-language hinders the acquisition of the English language.

"(d) It makes deaf-mutes associate together in adult life, and avoid the society of hearing people.

"(e) It thus causes the intermarriage of deaf-mutes and the propagation of their physical defect.

"5. Written words can be associated directly with the ideas they express, without the intervention of signs, and written English can be taught to deaf children by usage so as to become their vernacular.

"6. A language can only be made vernacular by constant use as a means of communication, without translation.

"7. Deaf children who are familiar with the English language in either its written or spoken forms can be taught to understand the utterances of their friends by watching the mouth.

"8. The requisites to the art of speech-reading are:

"(a) An eye trained to distinguish quickly those movements of the vocal organs that are visible (independently of the meaning of what is uttered);

"(b) A knowledge of *homophenes*—that is, a knowledge of those words that present the same appearance to the eye; and,

"(c) Sufficient familiarity with the English language to enable the speech reader to judge by context which word of a homophenous group is the word intended by the speaker.

7. From what has been said above it will be seen that we have in actual operation the elements necessary to compel deaf-mutes to select as their partners in life persons who are familiar with the gesture language. This practically limits their selection to deaf-mutes and to hearing persons related to deaf-mutes. They do select such partners in marriage, and a certain proportion of their children inherit their physical defect. We are on the way therefore towards the formation of a deaf variety of the human race. Time alone is necessary to accomplish the result.

If we desired such a result what more could we do to hasten the end in view? We might attempt to formulate some plan which should lead the deaf children of deaf-mutes to marry one another instead of marrying deaf-mutes who had not inherited their deafness; or to marry hearing persons belonging to families in which deafness is hereditary. If, for instance, a number of the large deaf-mute families of the United States—families in which we know deafness to be hereditary—were to settle in a common place so as to form a community largely composed of deaf-mutes, then the deaf children born in the colony would be thrown into association with one another and would probably intermarry in adult life, or marry hearing persons belonging to the deaf-mute families. Though fewer in number than the original deaf settlers, they would probably be more prolific of deaf offspring; and each succeeding generation of deaf-mutes would increase the probability of the deaf-mute element being rendered permanent by heredity. Such a result would certainly ensue if the numbers of the deaf and dumb in the colony were constantly kept up by the immigration of congenital deaf-mutes from outside; and if a large proportion of the hearing children born in the colony were to leave and mingle with the outside world. Under such circumstances we might anticipate that a very few generations would suffice for the establishment of a permanent race of deaf-mutes with a language and literature of its own.

Plans for the formation of a deaf-mute community have a number of times been discussed by the deaf-mutes themselves. The idea originated in the action of Congress in endowing the American Asylum for Deaf-mutes at Hartford with a tract of land. Mon. Laurent Clerc, in conversation with some of the earlier pupils of the American Asylum, remarked that it would be a good

* See speech by Laurent Clerc, "American Annals of the Deaf and Dumb," vol. x, p. 212.

plan to sell a portion of the land for the benefit of the institution and retain the remainder as *head-quarters* for the deaf and dumb, to which they could emigrate after being educated.* This idea took root in the minds of the pupils of the American Asylum, and afterwards developed into a number of independent and eccentric schemes for the formation of a deaf-mute community. Some of the pupils before their graduation formed an agreement to emigrate to the West and settle in a common place.*

Then a number of years afterwards a deaf-mute publicly urged the formation of a deaf-mute commonwealth. Congress was to be petitioned to form a deaf-mute state or territory, &c. The details, though quite impracticable, brought forward the fact that a number of schemes of somewhat similar character were in the minds of deaf-mutes in different parts of the country. One deaf-mute publicly offered to contribute $5,000 towards such a scheme if others could be found to join him. It was urged that the natural affection of the parents would lead to the distribution of the land among their children, and that as the majority of their children could hear and speak the land would soon pass out of the control of the deaf-mutes themselves. This was to be remedied in various ways—as, for instance, by legislation—so as to secure descent in the deaf-mute line alone. The American Annals of the Deaf and Dumb became the channel of communication between the various thinkers.† The scheme that received most approbation was the purchase of a tract of land by a few of the wealthy deaf-mutes, who were to agree to sell out the land in small blocks to other deaf-mutes. The whole scheme was afterwards discussed at a convention of the deaf-mutes of New England, and was overthrown by the influence of the Rev. W. W. Turner, Mr. Laurent Clerc, and other teachers, in conjunction with the most intelligent of the deaf-mutes themselves. Since then the subject has not been publicly discussed, to my knowledge: but such a scheme is still favored by individual deaf-mutes, and may therefore be revived in organized shape at any time.‡

## CONCLUSION.

I think all will agree that the evidence shows a tendency to the formation of a deaf variety of the human race in America. What remedial measures can be taken to lessen or check this tendency? We shall consider the subject under two heads: (1) repressive, (2) preventive measures.

(1.) *Repressive measures.*—The first thought that occurs in this connection is that the intermarriage of deaf-mutes might be forbidden by legislative enactment. So long, however, as deaf-mutes of both sexes continue to associate together in adult life, legislative interference with marriage might only promote immorality. But, without entirely prohibiting intermarriage, might not the marriages of the deaf be so regulated as to reduce the probabilities of the production of deaf offspring to a minimum? For instance, a law forbidding congenitally deaf persons from intermarrying would go a long way towards checking the evil. Such a law might, however, become inoperative on account of the impossibility of proving that a person had been born deaf.

Legislation forbidding the intermarriage of persons belonging to families containing more than one deaf-mute would be more practicable. This would cover the intermarriage of hearing persons belonging to such families, and also the case of a consanguineous marriage in a deaf-mute family.

In order to justify the passage of such an act, however, the results of intermarriages of this kind should be more fully investigated than is possible at the present time on account of limited

* See "American Annals of the Deaf and Dumb," vol. x, p. 73.

† See vol. x, pp. 72–90; 136–160; 212–215.

‡ Since this paper was read, a European philanthropist has commenced the colonization of a tract of land in Manitoba by deaf-mutes. I am informed by a friend who resides in Winnipeg that about 21 deaf-mutes, with their families, have already arrived from Europe and have settled upon the land. More are expected next year.

data. Steps should be taken towards the collection of special statistics, and the institutions should be urged to publish the materials in their possession. I wrote to the principals of all the institutions in the country, requesting them to forward to me such of their published reports as contained any of the required statistics. Although my request was honored by a response from a large number of institutions, the information contained in the reports in reference to the subject of inquiry was generally of the most meagre description.

Among repressive measures should perhaps be included the influence of friends to prevent undesirable intermarriages. While such action might affect individual cases it could not greatly influence the general result. For there is no subject on which a man will so little brook interference as one of this kind where his affections are involved.

*A due consideration of all the objections renders it doubtful whether legislative interference with the marriage of the deaf would be advisable.*

(2.) *Preventive measures.*—The most promising method of lessening the evil appears to lie in the adoption of preventive measures. In our search for such measures we should be guided by the following principle: (1.) *Determine the causes that promote intermarriages among the deaf and dumb; and* (2) *remove them.*

The immediate cause is undoubtedly the preference that adult deaf-mutes exhibit for the companionship of deaf-mutes rather than that of hearing persons. Among the causes that contribute to bring about this preference we may note: (1) segregation for the purposes of education, and (2) the use, as a means of communication, of a language which is different from that of the people. These then are two of the points that should be avoided in the adoption of preventive measures. Nearly all the other causes I have investigated are ultimately referable to these.

Segregation really lies at the root of the whole matter; for from this the other causes have themselves been evolved by the operation of the natural law of adaptation to the environment.

We commence our efforts on behalf of the deaf-mute by changing his social environment. The tendency is then towards accommodation to the new conditions. In process of time the adaptation becomes complete; and when, at last, we restore him to the world as an adult, he finds that the social conditions to which he has become accustomed do not exist outside of his school life. His efforts are then directed to the restoration of these conditions with the result of intermarriage and a tendency to the formation of a deaf-mute community.

The grand central principle that should guide us, then, in our search for preventive measures should be *the retention of the normal environment during the period of education.* The natural tendency towards adaptation would then co-operate with instruction to produce accommodation to the *permanent* conditions of life.

The direction of change should therefore be towards the establishment of small schools, and the extension of the day-school plan. The practicability of any great development of day schools will depend upon the possibility of conducting very small schools of this kind economically to the State; for the scattered condition of the deaf and dumb in the community precludes the idea of large day schools, excepting in the great centers of population. The principle referred to above indicates that such schools should be of the minimum size possible; for the school that would most perfectly fulfil the condition required would contain only one deaf child. It also points to the advisability of coeducation with hearing children—but this is not practicable to any great extent. No instruction can be given through the ear, and complete coeducation would only therefore be possible by a change in the methods of teaching hearing children. It is useless to expect that such a change would be made for the benefit of the deaf and dumb on account of their limited number.

Partial coeducation is, however, possible, for some studies are pursued in the common schools in which information is gained through the eye. For instance, deaf-mutes could profitably enter the same classes with hearing children for practice in writing, drawing, map-drawing, arithmetic on the black-board, sewing, &c. For other subjects special methods of instruction would be necessary, and these demand the employment of special teachers. They do not, however, necessitate special schools or buildings, and a small room in a public school building would accommodate as many deaf children as one teacher could successfully instruct. Considerations of economy render advisable the appropriation of a room of this kind, as the appliances of a large school might thus be obtained without special outlay.

The average *per capita* cost of the education of a deaf child in an American institution is $223.28 per annum.* Very small day schools could be maintained at no greater cost. The cost, at an institution, however, includes board and industrial training. On the day-school plan the parents would generally assume the expense of maintenance, and some special provision would have to be made for industrial training. This need give no concern, for so many deaf-mutes are earning their livelihood by trades which they were *not* taught in the institutions as to demonstrate the practicability of apprenticing deaf-mutes in ordinary shops.

The indications are that in all places where three or four deaf children could be brought together near their homes the cost would be no more to form them into a class in the nearest public school building under a special teacher than to send them to an institution. On the basis of the average *per capita* cost at an institution the sum of $669.84 would be received for three, and $893.12 for four pupils; and such sums would probably be sufficient to pay the salary of a special teacher, as well as to cover incidental expenses.

If this is so the day-school system could be made to penetrate into the smaller centers of population as well as into the large cities, in which case it would exert a considerable influence as a remedial agent. The plan of forming small classes of deaf children in public school buildings recommends itself as affording the closest approximation possible, on the large scale, to the normal conditions of life.

Segregation during education has not only favored the tendency towards the formation of a race of deaf-mutes, but has led to the evolution of a special language adapted for the use of such a race—"the sign-language of the deaf and dumb." This is especially true in America where the sign-language is employed by a large majority of the teachers in instructing their pupils. In foreign countries the vast majority employ, for this purpose, the ordinary language of the people. This will fully appear by reference to Table V in the Appendix.

The lack of articulate speech should also be noted as an indirect cause of segregation in adult life, operating to separate deaf-mutes from hearing persons. Hence, instruction in articulation and speech-reading should be given to every pupil.

This is done in Germany. Indeed, in 1882, more than 65 per cent. of all the deaf and dumb in foreign schools were being taught to speak and understand the speech of others, whereas in America less than 9 per cent. were to be found in oral schools.†

According to more recent statistics compiled by the Clarke Institution‡ we find that in May, 1883, about 14 per cent. of the deaf and dumb in American institutions were using speech in the

*See Table X in the Appendix.

†See American Annals of the Deaf and Dumb, vol. xxviii, pp. 47–61; also, Table V, in the Appendix—from which it will appear that of 7,155 American deaf-mutes, only 584, or less than 9 per cent., were to be found in oral schools; whereas of 19,318 deaf-mutes in foreign schools, 12,662, or more than 65 per cent., were taught to speak in purely oral schools.

‡See Appendix to Sixteenth Annual Report of the Clarke Institution. See, also, Table Y in the Appendix. Complete returns were not obtained, but the cases noted number 6,232, thus comprehending the vast majority of the pupils under instruction in May, 1883. Of these 886, or 14 per cent., were under oral instruction; 1,105, or 18 per cent., received occasional instruction in speech in sign institutions; and 4,241 received no instruction in articulation whatever.

school-room as the language of communication with their teachers; 18 per cent. were taught to speak as an accomplishment, and 68 per cent. received no instruction whatever in articulation.

Nearly one-third of the teachers of the deaf and dumb in America are themselves deaf,* and this must be considered as another element favorable to the formation of a deaf race—to be therefore avoided.

The segregation of deaf-mutes, the use of the sign language, and the employment of deaf teachers produce an environment that is unfavorable to the cultivation of articulation and speech-reading, and that sometimes causes the disuse of speech by speaking pupils who are only deaf.

Having shown the tendency to the formation of a deaf variety of the human race in America, and some of the means that should be taken to counteract it, I commend the whole subject to the attention of scientific men.

* See American Annals of the Deaf and Dumb (January, 1883), vol. xxviii, pp. 56–57. Out of 481 teachers 154, or 32 per cent., were deaf.

# APPENDIX.

1. Tables A to M give an analysis of 3,726 cases of deaf-mutes from the American Asylum and Illinois Institution. For this analysis I am indebted to Mr. Franck Z. Maguire, of Washington, D. C.; and I have personally verified his results. The relation of the tables to one another will be understood from the following classification:

*Classification of Tables A to K.*

| | | |
|---|---|---|
| Total number of pupils of the American Asylum and Illinois Institution (see Table A). | Whose deafness was stated to be *congenital* (see Table B). | Recorded to have deaf-mute relatives (see Table E). |
| | | Recorded as sporadic cases (see Table F). |
| | Whose deafness was stated to be *non-congenital* (see Table C). | Recorded to have deaf-mute relatives (see Table G). |
| | | Recorded as sporadic cases (see Table H). |
| | The cause of whose deafness was *not stated* (see Table D). | Recorded to have deaf-mute relatives (see Table I). |
| | | Recorded as sporadic cases (see Table J). |

Table A gives the summation of Tables B, C, and D.

Table B gives the summation of Tables E and F.

Table C gives the summation of Tables G and H.

Table D gives the summation of Tables I and J.

In Table K the non-congenitally deaf pupils are classified according to period of birth and according to period when deafness occurred.

In Table L the non-congenitally deaf pupils of the American Asylum are classified according to the period when hearing was lost, and according to the diseases that caused deafness.

In Table M the non-congenitally deaf pupils of the Illinois Institution are classified according to the period when hearing was lost, and according to the diseases that caused deafness.

2. Tables N, O, P, Q relate to the Tenth Census of the United States (1880), and give the results of an analysis of 22,472 cases of deaf-mutes from the census returns. (See communication by the Rev. Fred. D. Wines upon the 1880 census of the deaf and dumb; proceedings of the 10th convention of American instructors of the deaf and dumb, Jacksonville, Ill., August, 1882, pp. 122–128, published with the 21st biennial report of the Illinois Institution for the Deaf and Dumb.)

Table N gives an analysis of 22,472 cases of deaf-mutes living June 1, 1880, showing the number who became deaf each year since the year 1770.

Table O shows the number of these deaf-mutes who became deaf each year since 1873, separating the congenital from the non-congenital cases.

Table P classifies the 22,472 cases by periods of five years and reduces the number who became deaf in each quinquennial period to a percentage of the whole on a basis of 10,000 cases in all.

Table Q classifies the 22,472 cases by periods of five years and separates the congenital from the non-congenital cases.

3. Table R shows the number of deaf-mutes in the United States living June 1, 1880, arranged according to race and sex and according to cause of deafness. The materials for this table have

been furnished in advance of the publication of the census returns by the courtesy of General Seaton, General Superintendent of the Census. (See "Science," vol. iii, p. 244: and "American Annals of the Deaf and Dumb," vol. xxix p, 160.)

4. Table S shows (*a*) the number of schools and institutions for the education of the deaf and dumb in the United States, 1883; (*b*) the date of opening of each institution: (*c*) the number of deaf children under instruction, 1883; and (*d*), the total number of pupils that have been received into the institutions. These particulars have been obtained from the "American Annals of the Deaf and Dumb," vol. xxix, pp. 90–91. The table also shows (*e*) the number of deaf children whose parents were deaf-mutes who have been received into the institutions. These particulars have been received directly from the principals or superintendents of the institutions and schools in answer to a circular-letter of inquiry. The total number of such pupils cannot be ascertained from the table as some of the institutions have not yet made returns.

5. Table T gives an analysis of 215 cases of deaf-mutes whose parents were deaf.

6. In Table U the total population of the country, the congenitally deaf population, and the deaf-mutes who have both parents deaf, are classified according to their period of birth, and the number of persons born in each period has been reduced to a percentage of the whole.

7. Table V contains a tabular statement of the institutions of the world in 1882, showing the methods of instruction employed. This Table is taken from the "American Annals of the Deaf and Dumb," for January, 1883, vol. xxviii, p. 61.

8. Table W gives a list of those pupils of our institutions for the deaf and dumb who are stated to have deaf parents. The information has been obtained directly from the principals and superintendents of the institutions in answer to a letter of inquiry.

9. Table X shows the *per capita* cost of the education of a deaf child in an American institution. This table was prepared by the principal of the Illinois Institution from materials published in the American Annals of the Deaf and Dumb, and from other materials privately collected and published in the Twenty-first Biennial Report of the Illinois Institution (1882), pp. 16–17.

10. Table Y contains a tabular statement concerning the teaching of articulation in the institutions of the United States in May, 1883. The information was obtained by the principal of the Clarke Institution, Northampton, Mass., directly from the principals of the other institutions in reply to a circular of inquiry. See Appendix B, Sixteenth Annual Report of the Clarke Institution for Deaf-Mutes, September 1, 1883.

11. Appendix Z contains an examination of the marriages of the pupils of the American Asylum and Illinois Institution by the light of the theory of Probabilities, with the object of determining approximately the proportion of the congenitally deaf who marry congenital deaf-mutes. This investigation has been kindly undertaken by Prof. Simon Newcomb, to whom I am indebted for the results obtained.

TABLE A.—*Total number of pupils.*

AMERICAN ASYLUM.

| Period of birth. | Grand total. Total. | Grand total. Males. | Grand total. Females. | Not recorded to have married. Total. | Not recorded to have married. Males. | Not recorded to have married. Females. | Married. Total. Total. Total. | Married. Total. Total. Recorded to have deaf children. | Married. Total. Total. Recorded number of deaf children born to the pupils. | Married. Total. Males. Total. | Married. Total. Males. Recorded to have deaf children. | Married. Total. Males. Recorded number of deaf children born to the males. | Married. Total. Females. Total. | Married. Total. Females. Recorded to have deaf children. | Married. Total. Females. Recorded number of deaf children born to the females. | Married to deaf mutes. Total. Total. | Married to deaf mutes. Total. Recorded to have deaf children. | Married to deaf mutes. Total. Recorded number of deaf children born to the pupils. | Married to deaf mutes. Males. Total. | Married to deaf mutes. Males. Recorded to have deaf children. | Married to deaf mutes. Males. Recorded number of deaf children born to the males. | Married to deaf mutes. Females. Total. | Married to deaf mutes. Females. Recorded to have deaf children. | Married to deaf mutes. Females. Recorded number of deaf children born to the females. | Not recorded to have married deaf mutes. Total. Total. | Not recorded to have married deaf mutes. Total. Recorded to have deaf children. | Not recorded to have married deaf mutes. Total. Recorded number of deaf children born to the pupils. | Not recorded to have married deaf mutes. Males. Total. | Not recorded to have married deaf mutes. Males. Recorded to have deaf children. | Not recorded to have married deaf mutes. Males. Recorded number of deaf children born to the males. | Not recorded to have married deaf mutes. Females. Total. | Not recorded to have married deaf mutes. Females. Recorded to have deaf children. | Not recorded to have married deaf mutes. Females. Recorded number of deaf children born to the females. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1760–1769 ... | 1 | 1 | ..... | 1 | 1 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | | ..... | ..... | ..... | ..... | ..... | ..... | ..... | .. | .. | .. | .. | .. | | | .. | .. | | . |
| 1770–1779 ... | 2 | 1 | 1 | 1 | ..... | 1 | 1 | ..... | ..... | 1 | ..... | ..... | . | ..... | . | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 1 | ..... | ..... | 1 | | .. | .. | | |
| 1780–1789 ... | 7 | 4 | 3 | 5 | 2 | 3 | 2 | ..... | ..... | 2 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | . | | 2 | . | .. | 2 | | .. | | | |
| 1790–1799 ... | 44 | 24 | 20 | 27 | 12 | 15 | 17 | ..... | ..... | 12 | ..... | ..... | 5 | ..... | . | 9 | ..... | | 7 | ..... | ..... | 2 | .. | .. | 8 | ... | . | 5 | | | 3 | | |
| 1800–1809 ... | 158 | 95 | 63 | 78 | 42 | 36 | 80 | 4 | ..... | 53 | 2 | 6 | 27 | 2 | 5 | 46 | 3 | ... | 27 | 1 | 3 | 19 | 2 | 5 | 34 | 1 | 3 | 26 | 1 | 3 | 8 | | |
| 1810–1819 ... | 276 | 152 | 124 | 127 | 72 | 55 | 149 | 11 | ..... | 80 | 6 | 15 | 69 | 5 | 15 | 122 | 10 | .... | 64 | 6 | 15 | 58 | 4 | 10 | 27 | 1 | 5 | 16 | | ... | 11 | 1 | 5 |
| 1820–1829 ... | 288 | 170 | 118 | 144 | 90 | 54 | 144 | 8 | ..... | 80 | 5 | 9 | 64 | 3 | 5 | 111 | 6 | ..... | 61 | 4 | 6 | 50 | 2 | 2 | 33 | 2 | 6 | 19 | 1 | 3 | 14 | 1 | |
| 1830–1839 ... | 324 | 184 | 140 | 195 | 112 | 83 | 129 | 5 | ..... | 72 | 3 | 6 | 57 | 2 | 2 | 117 | 5 | ..... | 63 | 3 | 6 | 54 | 2 | 2 | 12 | . | .. | 9 | . | .. | 3 | | |
| 1840–1849 ... | 387 | 214 | 173 | 291 | 169 | 122 | 96 | .... | ..... | 45 | ..... | ..... | 51 | .... | .. | 81 | .... | | 36 | .... | .. | 45 | | .. | 15 | .. | | 9 | | . | 6 | | |
| 1850–1859 ... | 387 | 231 | 156 | 363 | 222 | 141 | 24 | 1 | ..... | 9 | ..... | .... | 15 | 1 | 1 | 16 | ..... | .... | 5 | | | 11 | . | .. | 8 | 1 | 1 | 4 | | | 4 | 1 | 1 |
| 1860–1869 ... | 228 | 140 | 88 | 228 | 140 | 88 | ..... | ..... | ..... | ..... | .... | | .... | ..... | .... | . | .... | | ..... | ..... | ..... | ... | | .. | . | | .. | | .. | . | | | |
| Unknown | 4 | 3 | 1 | 4 | 3 | 1 | .... | ..... | ..... | ..... | ... | ..... | .... | ..... | ..... | .. | ........ | .. | ..... | .... | .... | ..... | .. | .. | . | .. | . | | | | | . | |
| Total ... | 2,106 | 1,219 | 887 | 1,464 | 865 | 599 | 642 | 29 | ([1]) | 354 | 16 | 36 | 288 | 13 | 28 | 502 | 24 | ([1]) | 263 | 14 | 30 | 239 | 10 | 19 | 140 | 5 | 15 | 91 | 2 | 6 | 49 | 3 | 9 |

TABLE A.—*Total number of pupils*—Continued.

ILLINOIS INSTITUTION.

| Period of birth. | Grand total. | | | Not recorded to have married. | | | Married. Total. Total. | | | Married. Total. Males. | | | Married. Total. Females. | | | Married to deaf mutes. Total. | | | Married to deaf mutes. Males. | | | Married to deaf mutes. Females. | | | Not recorded to have married deaf mutes. Total. | | | Not recorded to have married deaf mutes. Males. | | | Not recorded to have married deaf mutes. Females. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total. | Males. | Females. | Total. | Males. | Females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. |
| 1810–1819 | 5 | 1 | 4 | 2 | ...... | 2 | 3 | 1 | ...... | 1 | 1 | 1 | 2 | .... | ..... | 2 | ...... | ...... | ...... | ...... | ...... | 2 | ... | .. | 1 | 1 | 1 | 1 | 1 | 1 | ... | ... | .. |
| 1820–1829 | 27 | 12 | 15 | 16 | 4 | 12 | 11 | 2 | ...... | 8 | 2 | 2 | 3 | ...... | ..... | 9 | 2 | ...... | 7 | 2 | 2 | 2 | .... | .... | 2 | ... | .. | 1 | .. | ... | 1 | .. | ... |
| 1830–1839 | 127 | 73 | 54 | 92 | 55 | 37 | 35 | 6 | ...... | 18 | 2 | 3 | 17 | 4 | 5 | 31 | 6 | ...... | 15 | 2 | 3 | 16 | 4 | 5 | 4 | .. | ... | 3 | .. | .. | 1 | ... | .. |
| 1840–1849 | 268 | 161 | 107 | 202 | 126 | 76 | 66 | 3 | ...... | 35 | 1 | 2 | 31 | 2 | 3 | 58 | 3 | ...... | 32 | 1 | 2 | 26 | 2 | 3 | 8 | ... | .... | 3 | .. | .. | 5 | .. | .. |
| 1850–1859 | 414 | 220 | 194 | 368 | 197 | 171 | 46 | 2 | ..... | 23 | 2 | 2 | 23 | ...... | .... | 41 | 2 | ...... | 21 | 2 | 2 | 20 | .. | ... | 5 | .... | .. | 2 | .. | ... | 3 | .. | ... |
| 1860–1869 | 573 | 330 | 243 | 561 | 325 | 236 | 12 | ...... | ...... | 5 | ...... | ...... | 7 | ...... | .... | 11 | ...... | .... | 5 | ...... | ...... | 6 | .. | .. | 1 | ... | . | .. | .. | .. | 1 | . | ... |
| 1870–1879 | 201 | 114 | 87 | 201 | 114 | 87 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | .... | ... | .. | ... | ... | ... | .. | .. | .. | .. | .. | ... |
| Unknown | 5 | 3 | 2 | 4 | 2 | 2 | 1 | ...... | ...... | 1 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ... | ... | 1 | ... | . | 1 | .. | .. | .. | .. | .. |
| Total | 1,620 | 914 | 706 | 1,446 | 823 | 623 | 174 | 14 | (?) | 91 | 8 | 10 | 83 | 6 | 8 | 152 | 13 | (?) | 80 | 7 | 9 | 72 | 6 | 8 | 22 | 1 | 1 | 11 | 1 | 1 | 11 | ... | ... |

TABLE B.—*Congenitally deaf pupils.*

AMERICAN ASYLUM.

| Period of birth. | Grand total. | | | Not recorded to have married. | | | MARRIED. Total. Total. | | | Total. Males. | | | Total. Females. | | | Married to deaf-mutes. Total. | | | Married to deaf-mutes. Males. | | | Married to deaf-mutes. Females. | | | Not recorded to have married deaf-mutes. Total. | | | Not recorded to have married deaf-mutes. Males. | | | Not recorded to have married deaf-mutes. Females. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total. | Males. | Females. | Total. | Males. | Females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total | Recorded to have deaf children. | Recorded number of deaf children born to the females. |
| 1760–1769 .... | 1 | 1 | ...... | 1 | 1 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | .. |
| 1770–1779 ... | 1 | ...... | 1 | 1 | ...... | 1 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| 1780–1789 ... | 6 | 4 | 2 | 4 | 2 | 2 | 2 | ...... | ...... | 2 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 2 | .. | ... | 2 | ... | ... | .. | ... | |
| 1790–1799 .. | 27 | 14 | 13 | 20 | 9 | 11 | 7 | ...... | ...... | 5 | ...... | ...... | 2 | .... | ...... | 4 | ...... | ...... | 4 | ...... | ...... | ...... | ... | .. | 3 | ...... | ... | 1 | .. | ... | 2 | .. | . |
| 1800–1809 ... | 73 | 42 | 31 | 40 | 21 | 19 | 33 | 1 | ...... | 21 | 2 | 6 | 12 | 2 | 5 | 22 | 3 | ...... | 13 | 1 | 3 | 9 | 2 | 5 | 11 | 1 | 3 | 8 | 1 | 3 | 3 | .. | ... |
| 1810–1819 .... | 114 | 62 | 52 | 60 | 34 | 26 | 54 | 8 | ...... | 28 | 3 | 8 | 26 | 5 | 15 | 42 | 7 | ...... | 20 | 3 | 8 | 22 | 4 | 10 | 12 | 1 | 5 | 8 | .. | .. | 4 | 1 | 5 |
| 1820–1829 .... | 153 | 83 | 70 | 75 | 44 | 31 | 78 | 6 | ...... | 39 | 4 | 8 | 39 | 2 | 4 | 60 | 4 | ...... | 30 | 3 | 5 | 30 | 1 | 1 | 18 | 2 | 6 | 9 | 1 | 3 | 9 | 1 | 3 |
| 1830–1839 ... | 173 | 95 | 78 | 112 | 62 | 50 | 61 | 2 | ...... | 33 | 1 | 1 | 28 | 1 | 1 | 54 | 2 | ...... | 29 | 1 | 1 | 25 | 1 | 1 | 7 | .. | . | 4 | .. | .. | 3 | | . |
| 1840–1849 .... | 198 | 102 | 96 | 140 | 77 | 63 | 58 | ...... | ...... | 25 | ...... | ...... | 33 | ...... | ...... | 54 | ...... | .... | 23 | ...... | ...... | 31 | ... | ... | 4 | .. | .. | 2 | .. | .. | 2 | .. | |
| 1850–1859 ... | 144 | 86 | 58 | 141 | 85 | 56 | 3 | ...... | ...... | 1 | ...... | ... | 2 | ...... | ...... | 3 | ...... | ...... | 1 | ...... | .... | 2 | ... | . | .. | ... | ... | .. | .. | .. | .. | .. | .. |
| 1860–1869 .... | 83 | 51 | 32 | 83 | 51 | 32 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ... | ... | ... | ... | .... | .. | ... | | .. | ... | |
| Total .. | 973 | 540 | 433 | 677 | 386 | 291 | 296 | 20 | (?) | 154 | 10 | 23 | 142 | 10 | 25 | 239 | 16 | (?) | 120 | 8 | 17 | 119 | 8 | 17 | 57 | 4 | 14 | 34 | 2 | 6 | 23 | 2 | 8 |

TABLE B.—*Congenitally deaf pupils*—Continued.

ILLINOIS INSTITUTION.

| Period of birth. | Grand total. | | | Not recorded to have married. | | | MARRIED. Total. Total. | | | Total. Males. | | | Total. Females. | | | Married to deaf mutes. Total. | | | Married to deaf mutes. Males. | | | Married to deaf mutes. Females. | | | Not recorded to have married deaf-mutes. Total. | | | Not recorded to have married deaf-mutes. Males. | | | Not recorded to have married deaf-mutes. Females. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total. | Males. | Females. | Total. | Males. | Females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. |
| 1810–1819 | 1 | ..... | 1 | ..... | .... | ..... | 1 | ..... | ..... | .... | .... | ..... | 1 | .... | .... | 1 | .... | .... | .... | .... | .... | 1 | | | | | | | | | | | |
| 1820–1829 | 13 | 6 | 7 | 8 | 1 | 7 | 5 | 1 | .... | 5 | 1 | 1 | ..... | ..... | ..... | 4 | 1 | .... | 4 | 1 | 1 | ..... | ..... | ..... | 1 | ... | ... | 1 | .. | . | | | |
| 1830–1839 | 52 | 33 | 19 | 36 | 25 | 11 | 16 | 4 | ..... | 8 | 1 | 1 | 8 | 3 | 4 | 16 | 4 | .... | 8 | 1 | 1 | 8 | 3 | 4 | .. | .. | . | . | ... | .. | .... | .. | |
| 1840–1849 | 77 | 43 | 34 | 55 | 32 | 23 | 22 | 1 | ..... | 11 | | ..... | 11 | 1 | 2 | 20 | 1 | ..... | 10 | ..... | ..... | 10 | 1 | 2 | 2 | .. | .. | 1 | .. | . | 1 | | .. |
| 1850–1859 | 140 | 73 | 67 | 122 | 65 | 57 | 18 | ..... | .... | 8 | ..... | ..... | 10 | .... | ..... | 17 | .... | . | 8 | ..... | ..... | 9 | .. | . | 1 | .. | .. | . | .. | | 1 | | |
| 1860–1869 | 105 | 63 | 42 | 104 | 63 | 41 | 1 | ..... | ..... | .... | ..... | ..... | 1 | ..... | ..... | 1 | ..... | ..... | .. | ... | ..... | 1 | .. | .. | .. | | . | | | | | | |
| 1870–1879 | 29 | 19 | 10 | 29 | 19 | 10 | .... | ..... | .... | .... | ..... | .... | ..... | ..... | ..... | .... | ..... | .... | ..... | ..... | | ..... | .. | . | ... | ... | .. | | | | . | | |
| Unknown | 1 | 1 | ..... | ..... | .... | ..... | 1 | ..... | ..... | 1 | ..... | ..... | .... | .... | ..... | .... | ..... | ..... | .... | ..... | .... | ..... | . | .. | 1 | .. | . | 1 | .. | | | | |
| Total | 418 | 238 | 180 | 354 | 205 | 149 | 64 | 6 | (4) | 33 | 2 | 2 | 31 | 4 | 6 | 59 | 6 | (4) | 30 | 2 | 2 | 29 | 1 | 6 | 5 | ... | .. | 3 | | .. | 2 | | . |

TABLE C.—*Non-congenitally deaf pupils.*

AMERICAN ASYLUM.

| Period of birth. | Grand total | | | Not recorded to have married. | | | MARRIED. Total. Total. | | | MARRIED. Total. Males. | | | MARRIED. Total. Females. | | | Married to deaf-mutes. Total. | | | Married to deaf-mutes. Males. | | | Married to deaf-mutes. Females. | | | Not recorded to have married deaf-mutes. Total. | | | Not recorded to have married deaf-mutes. Males. | | | Not recorded to have married deaf-mutes. Females. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total. | Males. | Females. | Total. | Males. | Females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. |
| 1760–1769 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1770–1779 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1780–1789 | 1 | | 1 | 1 | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1790–1799 | 12 | 7 | 5 | 4 | 2 | 2 | 8 | | | 5 | | | 3 | | | 5 | | | 3 | | | 2 | | | 3 | | | 2 | | | 1 | | |
| 1800–1809 | 70 | 43 | 27 | 30 | 16 | 14 | 40 | | | 27 | | | 13 | | | 20 | | | 10 | | | 10 | | | 20 | | | 17 | | | 3 | | |
| 1810–1819 | 147 | 81 | 66 | 58 | 32 | 26 | 89 | 3 | | 49 | 3 | 7 | 40 | | | 76 | 3 | | 42 | 3 | 7 | 34 | | | 13 | | | 7 | | | 6 | | |
| 1820–1829 | 124 | 79 | 45 | 62 | 41 | 21 | 62 | 2 | | 38 | 1 | 1 | 24 | 1 | 1 | 48 | 2 | | 29 | 1 | 1 | 19 | 1 | 1 | 14 | | | 9 | | | 5 | | |
| 1830–1839 | 146 | 85 | 61 | 79 | 46 | 33 | 67 | 2 | | 39 | 2 | 5 | 28 | | | 62 | 2 | | 34 | 2 | 5 | 28 | | | 5 | | | 5 | | | | | |
| 1840–1849 | 182 | 109 | 73 | 145 | 89 | 56 | 37 | | | 20 | | | 17 | | | 26 | | | 13 | | | 13 | | | 11 | | | 7 | | | 4 | | |
| 1850–1859 | 224 | 137 | 87 | 206 | 130 | 76 | 18 | 1 | | 7 | | | 11 | 1 | 1 | 12 | | | 4 | | | 8 | | | 6 | 1 | 1 | 3 | | | 3 | 1 | 1 |
| 1860–1869 | 133 | 80 | 53 | 133 | 80 | 53 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Unknown | 1 | 1 | | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total | 1,040 | 622 | 418 | 719 | 437 | 282 | 321 | 8 | (?) | 185 | 6 | 13 | 136 | 2 | 2 | 249 | 7 | (¹) | 135 | 6 | 13 | 114 | 1 | 1 | 72 | 1 | 1 | 50 | | | 22 | 1 | 1 |

TABLE C.—*Non-congenitally deaf pupils*—Continued.

ILLINOIS INSTITUTION.

| Period of birth. | Grand total. | | | Not recorded to have married. | | | MARRIED. | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Total. | | | | | | | | | Married to deaf-mutes. | | | | | | | | | Not recorded to have married deaf mutes. | | | | | | | | |
| | | | | | | | Total | | | Males. | | | Females. | | | Total. | | | Males. | | | Females. | | | Total. | | | Males. | | | Females. | | |
| | Total. | Males. | Females. | Total. | Males. | Females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. |
| 1810–1819 | 2 | 1 | 1 | 1 | .... | 1 | 1 | 1 | ..... | 1 | 1 | 1 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | .. | .. | 1 | 1 | 1 | 1 | 1 | 1 | .. | .. | ... |
| 1820–1829 | 11 | 4 | 7 | 6 | 2 | 4 | 5 | ..... | .... | 2 | ..... | ..... | 3 | ..... | ..... | 4 | ..... | .... | 2 | ..... | .... | 2 | .. | ... | 1 | . | .. | .. | ... | .. | 1 | ... | .. |
| 1830–1839 | 58 | 29 | 29 | 41 | 20 | 21 | 17 | 1 | ..... | 9 | ..... | ..... | 8 | 1 | 1 | 14 | 1 | ..... | 6 | ..... | ..... | 8 | 1 | 1 | 3 | .. | .. | 3 | .. | ... | ... | ... | .. |
| 1840–1849 | 164 | 102 | 62 | 123 | 79 | 44 | 41 | 2 | .... | 23 | 1 | 2 | 18 | 1 | 1 | 36 | 2 | ..... | 21 | 1 | 2 | 15 | 1 | 1 | 5 | | . | 2 | .. | ... | 3 | .. | ... |
| 1850–1859 | 217 | 122 | 95 | 192 | 109 | 83 | 25 | 2 | ..... | 13 | 2 | 2 | 12 | ... | ..... | 22 | 2 | ..... | 11 | 2 | 2 | 11 | ... | ... | 3 | ... | .. | 2 | .. | ... | 1 | ... | .. |
| 1860–1869 | 364 | 206 | 158 | 358 | 202 | 156 | 6 | ..... | ..... | 4 | ..... | ..... | 2 | ..... | ..... | 6 | ..... | ..... | 4 | ..... | ..... | 2 | ..... | ..... | ... | .. | .. | . | ... | ... | .. | ... | ... |
| 1870–1879 | 129 | 69 | 60 | 129 | 69 | 60 | ..... | .... | .... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ... | ... | .. | ... | ... | .. | ... | .. | ... | ... |
| Unknown | 2 | 1 | 1 | 2 | 1 | 1 | .... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | .. | .. | .. | ... | . | .. | ... | ... | ... | ... | ... |
| Total | 947 | 534 | 413 | 852 | 482 | 370 | 95 | 6 | (1) | 52 | 4 | 5 | 43 | 2 | 2 | 82 | 5 | (2) | 44 | 3 | 4 | 38 | 2 | 2 | 13 | 1 | 1 | 8 | 1 | 1 | 5 | .... | .... |

TABLE D.—*Pupils the cause of whose deafness was not stated.*

AMERICAN ASYLUM.

| Period of birth. | Grand total. | | | Not recorded to have married. | | | MARRIED. Total. | | | | | | | | | MARRIED. Married to deaf-mutes. | | | | | | | | | MARRIED. Not recorded to have married deaf-mutes. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Total. | | | Males. | | | Females. | | | Total. | | | Males. | | | Females. | | | Total. | | | Males. | | | Females. | | |
| | Total. | Males. | Females. | Total. | Males. | Females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. |
| 1760–1769 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1770–1779 | 1 | 1 | | | | | 1 | | | 1 | | | | | | | | | | | | | | | 1 | | | 1 | | | | | |
| 1780–1789 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1790–1799 | 5 | 3 | 2 | 3 | 1 | 2 | 2 | | | 2 | | | | | | | | | | | | | | | 2 | | | 2 | | | | | |
| 1800–1809 | 15 | 10 | 5 | 8 | 5 | 3 | 7 | | | 5 | | | 2 | | | 4 | | | 4 | | | | | | 3 | | | 1 | | | 2 | | |
| 1810–1819 | 15 | 9 | 6 | 9 | 6 | 3 | 6 | | | 3 | | | 3 | | | 4 | | | 2 | | | 2 | | | 2 | | | 1 | | | 1 | | |
| 1820–1829 | 11 | 8 | 3 | 7 | 5 | 2 | 4 | | | 3 | | | 1 | | | 3 | | | 2 | | | 1 | | | 1 | | | 1 | | | | | |
| 1830–1839 | 5 | 4 | 1 | 4 | 4 | | 1 | 1 | | | | | 1 | 1 | 1 | 1 | 1 | | | | | 1 | 1 | 1 | | | | | | | | | |
| 1840–1849 | 7 | 3 | 4 | 6 | 3 | 3 | 1 | | | | | | 1 | | | 1 | | | | | | 1 | | | | | | | | | | | |
| 1850–1859 | 19 | 8 | 11 | 16 | 7 | 9 | 3 | | | 1 | | | 2 | | | 1 | | | | | | 1 | | | 2 | | | 1 | | | 1 | | |
| 1860–1869 | 12 | 9 | 3 | 12 | 9 | 3 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Unknown | 3 | 2 | 1 | 3 | 2 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total | 93 | 57 | 36 | 68 | 42 | 26 | 25 | 1 | (?) | 15 | | | 10 | 1 | 1 | 14 | 1 | (?) | 8 | | | 6 | 1 | 1 | 11 | | | 7 | | | 4 | | |

TABLE D.—*Pupils the cause of whose deafness was not stated*—Continued.

ILLINOIS INSTITUTION.

| Period of birth. | Grand total. | | | Not recorded to have married. | | | MARRIED. Total. Total. | | | Total. Males. | | | Total. Females. | | | Married to deaf-mutes. Total. | | | Married to deaf-mutes. Males. | | | Married to deaf-mutes. Females. | | | Not recorded to have married deaf-mutes. Total. | | | Not recorded to have married deaf-mutes. Males. | | | Not recorded to have married deaf-mutes. Females. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total. | Males. | Females. | Total. | Males. | Females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. |
| [illegible]19 | 2 | | 2 | 1 | | 1 | 1 | | | | | | 1 | | | 1 | | | | | | 1 | | | | | | | | | | | |
| 1820–1829 | 3 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | | | | 1 | 1 | | 1 | 1 | 1 | | | | | | | | | | | | |
| 1830–1839 | 17 | 11 | 6 | 15 | 10 | 5 | 2 | 1 | | 1 | 1 | 2 | 1 | | | 1 | 1 | | 1 | 1 | 2 | | | | 1 | | | | | | 1 | | |
| 1840–1849 | 27 | 16 | 11 | 24 | 15 | 9 | 3 | | | 1 | | | 2 | | | 2 | | | 1 | | | 1 | | | 1 | | | | | | 1 | | |
| 1850–1859 | 57 | 25 | 32 | 54 | 23 | 31 | 3 | | | 2 | | | 1 | | | 2 | | | 2 | | | | | | 1 | | | | | | 1 | | |
| 1860–1869 | 104 | 61 | 43 | 99 | 60 | 39 | 5 | | | 1 | | | 4 | | | 4 | | | 1 | | | 3 | | | 1 | | | | | | 1 | | |
| 1870–1879 | 43 | 26 | 17 | 43 | 26 | 17 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Unknown | 2 | 1 | 1 | 2 | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total | 255 | 142 | 113 | 240 | 136 | 104 | 15 | 2 | (?) | 6 | 2 | 3 | 9 | | | 11 | 2 | (?) | 6 | 2 | 3 | 5 | | | 4 | | | | | | 4 | | |

TABLE E.—*Congenitally deaf pupils recorded to have deaf-mute relatives other than children.*

AMERICAN ASYLUM.

| Period of birth. | Grand total. | | | Not recorded to have married. | | | MARRIED. | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Total married. | | | | | | | | | Married to deaf-mutes. | | | | | | | | | Not recorded to have married deaf-mutes. | | | | | | | | |
| | | | | | | | Total. | | | Males. | | | Females. | | | Total. | | | Males. | | | Females. | | | Total. | | | Males. | | | Females. | | |
| | Total. | Males. | Females. | Total. | Males. | Females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. |
| 1760-1769 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1770-1779 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1780-1789 | 5 | 3 | 2 | 4 | 2 | 2 | 1 | | | 1 | | | | | | | | | | | | | | | 1 | | | 1 | | | | | |
| 1790-1799 | 15 | 6 | 9 | 11 | 4 | 7 | 4 | | | 2 | | | 2 | | | 2 | | | 2 | | | | | | 2 | | | | | | 2 | | |
| 1800-1809 | 43 | 26 | 17 | 26 | 15 | 11 | 17 | 2 | | 11 | 1 | 3 | 6 | 1 | 2 | 11 | 1 | | 7 | | | 4 | 1 | 2 | 6 | 1 | 3 | 4 | 1 | 3 | 2 | | |
| 1810-1819 | 67 | 31 | 36 | 29 | 16 | 13 | 38 | 7 | | 15 | 2 | 7 | 23 | 5 | 15 | 32 | 6 | | 11 | 2 | 7 | 21 | 4 | 10 | 6 | 1 | 5 | 4 | | | 2 | 1 | 5 |
| 1820-1829 | 111 | 63 | 48 | 54 | 35 | 19 | 57 | 4 | | 28 | 3 | 7 | 29 | 1 | 3 | 41 | 2 | | 19 | 2 | 4 | 22 | | | 16 | 2 | 6 | 9 | 1 | 3 | 7 | 1 | 3 |
| 1830-1839 | 101 | 55 | 46 | 61 | 34 | 27 | 40 | 2 | | 21 | 1 | 1 | 19 | 1 | 1 | 34 | 2 | | 17 | 1 | 1 | 17 | 1 | 1 | 6 | | | 4 | | | 2 | | |
| 1840-1849 | 107 | 55 | 52 | 73 | 41 | 32 | 34 | | | 14 | | | 20 | | | 30 | | | 12 | | | 18 | | | 4 | | | 2 | | | 2 | | |
| 1850-1859 | 60 | 38 | 22 | 58 | 38 | 20 | 2 | | | | | | 2 | | | 2 | | | | | | 2 | | | | | | | | | | | |
| 1860-1869 | 38 | 22 | 16 | 38 | 22 | 16 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Unknown | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total | 547 | 299 | 248 | 354 | 207 | 147 | 193 | 15 | (?) | 92 | 7 | 18 | 101 | 8 | 21 | 152 | 11 | (?) | 68 | 5 | 12 | 84 | 6 | 13 | 41 | 4 | 14 | 24 | 2 | 6 | 17 | 2 | 8 |

TABLE E.—*Congenitally deaf pupils recorded to have deaf mute relatives other than children*—Continued.

ILLINOIS INSTITUTION.

| Period of birth. | Grand total | | | Not recorded to have married. | | | Married. | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Total. | | | | | | | | | Married to deaf-mutes. | | | | | | | | | Not recorded to have married deaf-mutes. | | | | | | | | | |
| | | | | | | | Total. | | | Males. | | | Females. | | | Total. | | | Males. | | | Females. | | | Total. | | | Males. | | | Females. | | | |
| | Total. | Males. | Females. | Total. | Males. | Females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. | |
| 1810–1819 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1820–1829 | 9 | 4 | 5 | 6 | 1 | 5 | 3 | 1 | | 3 | 1 | 1 | | | | 3 | 1 | | 3 | 1 | 1 | | | | | | | | | | | | | |
| 1830–1839 | 25 | 16 | 9 | 17 | 13 | 4 | 8 | 1 | | 3 | | | 5 | 1 | 1 | 8 | 1 | | 3 | | | 5 | 1 | 1 | | | | | | | | | | |
| 1840–1849 | 34 | 18 | 16 | 21 | 12 | 9 | 13 | | | 6 | | | 7 | | | 12 | | | 5 | | | 7 | | | 1 | | | 1 | | | | | | |
| 1850–1859 | 69 | 30 | 39 | 57 | 26 | 31 | 12 | | | 4 | | | 8 | | | 11 | | | 4 | | | 7 | | | 1 | | | | | | 1 | | | |
| 1860–1869 | 47 | 29 | 18 | 47 | 29 | 18 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1870–1879 | 11 | 8 | 3 | 11 | 8 | 3 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Unknown | 1 | 1 | | | | | | | | 1 | | | | | | | | | | | | | | | 1 | | | 1 | | | | | | |
| Total | 196 | 106 | 90 | 159 | 89 | 70 | 37 | 2 | (?) | 17 | 1 | 1 | 20 | 1 | 1 | 34 | 2 | (?) | 15 | 1 | 1 | 19 | 1 | 1 | 3 | | | 2 | | | 1 | | | |

TABLE F.—*Congenitally deaf pupils recorded as sporadic cases.*

AMERICAN ASYLUM.

| Period of birth. | Grand total. | | | Not recorded to have married. | | | MARRIED. Total. Total. | | | Total. Males. | | | Total. Females. | | | Married to deaf-mutes. Total. | | | Married to deaf-mutes. Males. | | | Married to deaf-mutes. Females. | | | Not recorded to have married deaf-mutes. Total. | | | Not recorded to have married deaf-mutes. Males. | | | Not recorded to have married deaf-mutes. Females. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total. | Males. | Females. | Total. | Males. | Females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. |
| 1760–1769 | 1 | 1 | | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1770–1779 | 1 | | 1 | 1 | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1780–1789 | 1 | 1 | | | | | 1 | | | 1 | | | | | | | | | | | | | | | 1 | | | 1 | | | | | |
| 1790–1799 | 12 | 8 | 4 | 9 | 5 | 4 | 3 | | | 3 | | | | | | 2 | | | 2 | | | | | | 1 | | | 1 | | | | | |
| 1800–1809 | 30 | 16 | 14 | 14 | 6 | 8 | 16 | 2 | | 10 | 1 | 3 | 6 | 1 | 3 | 11 | 2 | | 6 | 1 | 3 | 5 | 1 | 3 | 5 | | | 4 | | | 1 | | |
| 1810–1819 | 47 | 31 | 16 | 31 | 18 | 13 | 16 | 1 | | 13 | 1 | 1 | 3 | | | 10 | 1 | | 9 | 1 | 1 | 1 | | | 6 | | | 4 | | | 2 | | |
| 1820–1829 | 42 | 20 | 22 | 21 | 9 | 12 | 21 | 2 | | 11 | 1 | 1 | 10 | 1 | 1 | 19 | 2 | | 11 | 1 | 1 | 8 | 1 | 1 | 2 | | | | | | 2 | | |
| 1830–1839 | 72 | 40 | 32 | 51 | 28 | 23 | 21 | | | 12 | | | 9 | | | 20 | | | 12 | | | 8 | | | 1 | | | | | | 1 | | |
| 1840–1849 | 91 | 47 | 44 | 67 | 36 | 31 | 24 | | | 11 | | | 13 | | | 24 | | | 11 | | | 13 | | | | | | | | | | | |
| 1850–1859 | 84 | 48 | 36 | 83 | 47 | 36 | 1 | | | 1 | | | | | | 1 | | | 1 | | | | | | | | | | | | | | |
| 1860–1869 | 45 | 29 | 16 | 45 | 29 | 16 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Unknown | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total | 426 | 241 | 185 | 323 | 179 | 144 | 103 | 5 | (?) | 62 | 3 | 5 | 41 | 2 | 4 | 87 | 5 | (?) | 52 | 3 | 5 | 35 | 2 | 4 | 16 | | | 10 | | | 6 | | |

TABLE F.—*Congenitally deaf pupils recorded as sporadic cases*—Continued.

ILLINOIS INSTITUTION.

| Period of birth. | Grand total. | | | Not recorded to have married. | | | MARRIED. Total. Total. | | | Total. Males. | | | Total. Females. | | | Married to deaf-mutes. Total. | | | Married to deaf-mutes. Males. | | | Married to deaf-mutes. Females. | | | Not recorded to have married deaf-mutes. Total. | | | Not recorded to have married deaf-mutes. Males. | | | Not recorded to have married deaf-mutes. Females. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total. | Males. | Females. | Total. | Males. | Females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. |
| 1810–1819 | 1 | | 1 | | | | 1 | | | | | | 1 | | | 1 | | | | | | 1 | | | | | | | | | | | |
| 1820–1829 | 4 | 2 | 2 | 2 | | 2 | 2 | | | 2 | | | | | | 1 | | | 1 | | | | | | 1 | | | 1 | | | | | |
| 1830–1839 | 27 | 17 | 10 | 19 | 12 | 7 | 8 | 3 | | 5 | 1 | 1 | 3 | 2 | 3 | 8 | 3 | | 5 | 1 | 1 | 3 | 2 | 3 | | | | | | | | | |
| 1840–1849 | 43 | 25 | 18 | 34 | 20 | 14 | 9 | 1 | | 5 | | | 4 | 1 | 2 | 8 | 1 | | 5 | | | 3 | 1 | 2 | 1 | | | | | | 1 | | |
| 1850–1859 | 71 | 43 | 28 | 65 | 39 | 26 | 6 | | | 4 | | | 2 | | | 6 | | | 4 | | | 2 | | | | | | | | | | | |
| 1860–1869 | 58 | 34 | 24 | 57 | 34 | 23 | 1 | | | | | | 1 | | | 1 | | | | | | 1 | | | | | | | | | | | |
| 1870–1879 | 18 | 11 | 7 | 18 | 11 | 7 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Unknown | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total | 222 | 132 | 90 | 195 | 116 | 79 | 27 | 4 | (?) | 16 | 1 | 1 | 11 | 3 | 5 | 25 | 4 | (?) | 15 | 1 | 1 | 10 | 3 | 5 | 2 | | | 1 | | | 1 | | |

TABLE G.—*Non-congenitally deaf pupils recorded to have deaf-mute relatives other than children.*

AMERICAN ASYLUM.

| Period of birth. | Grand total. | | | Not recorded to have married. | | | MARRIED. Total. | | | | | | | | | Married to deaf-mutes. | | | | | | | | | Not recorded to have married deaf mutes. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Total. | | | Males. | | | Females. | | | Total. | | | Males. | | | Females. | | | Total. | | | Males. | | | Females. | | |
| | Total. | Males. | Females. | Total. | Males. | Females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. |
| 1760–1769 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1770–1779 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1780–1789 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1790–1799 | 4 | 1 | 3 | 1 | | 1 | 3 | | | 1 | | | 2 | | | 3 | | | 1 | | | 2 | | | | | | | | | | | |
| 1800–1809 | 12 | 8 | 4 | 7 | 5 | 2 | 5 | | | 3 | | | 2 | | | 2 | | | | | | 2 | | | 3 | | | 3 | | | | | |
| 1810–1819 | 6 | 3 | 3 | 1 | 1 | | 5 | | | 2 | | | 3 | | | 4 | | | 2 | | | 2 | | | 1 | | | | | | 1 | | |
| 1820–1829 | 14 | 7 | 7 | 8 | 3 | 5 | 6 | 1 | | 4 | | | 2 | 1 | 1 | 5 | 1 | | 3 | | | 2 | 1 | 1 | 1 | | | 1 | | | | | |
| 1830–1839 | 19 | 7 | 12 | 11 | 6 | 5 | 8 | | | 1 | | | 7 | | | 8 | | | 1 | | | 7 | | | | | | | | | | | |
| 1840–1849 | 26 | 13 | 13 | 20 | 12 | 8 | 6 | | | 1 | | | 5 | | | 4 | | | 1 | | | 3 | | | 2 | | | | | | 2 | | |
| 1850–1859 | 30 | 15 | 15 | 24 | 13 | 11 | 6 | 1 | | 2 | | | 4 | 1 | 1 | 4 | | | 1 | | | 3 | | | 2 | 1 | 1 | 1 | | | 1 | 1 | 1 |
| 1860–1869 | 14 | 6 | 8 | 14 | 6 | 8 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Unknown | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total | 125 | 60 | 65 | 86 | 46 | 40 | 39 | 2 | (?) | 14 | | | 25 | 2 | 2 | 30 | 1 | (?) | 9 | | | 21 | 1 | 1 | 9 | 1 | 1 | 5 | | | 4 | 1 | 1 |

TABLE G.—*Non-congenitally deaf pupils recorded to have deaf-mute relatives other than children*—Continued.

ILLINOIS INSTITUTION.

| Period of birth. | Grand total. | | | Not recorded to have married. | | | MARRIED. Total. | | | | | | | | | Married to deaf-mutes. | | | | | | | | | Not recorded to have married deaf-mutes. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Total. | | | Males. | | | Females. | | | Total. | | | Males. | | | Females. | | | Total. | | | Males. | | | Females. | | |
| | Total. | Males. | Females. | Total. | Males. | Females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. |
| 1810–1819 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| 1820–1829 | 2 | 2 | .... | 1 | 1 | .... | 1 | .... | .... | 1 | .... | .... | .... | .... | .... | 1 | .... | .... | 1 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| 1830–1839 | 6 | 2 | 4 | 4 | 1 | 3 | 2 | .... | .... | 1 | .... | .... | 1 | .... | .... | 1 | .... | .... | .... | .... | .... | 1 | .... | .... | 1 | .... | .... | 1 | .... | .... | .... | .... | .... |
| 1840–1849 | 22 | 12 | 10 | 17 | 10 | 7 | 5 | 1 | .... | 2 | .... | .... | 3 | 1 | 1 | 5 | 1 | .... | 2 | .... | .... | 3 | 1 | 1 | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| 1850–1859 | 39 | 19 | 20 | 33 | 15 | 18 | 6 | 2 | .... | 4 | 2 | 2 | 2 | .... | .... | 6 | 2 | .... | 4 | 2 | 2 | 2 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| 1860–1869 | 37 | 24 | 13 | 37 | 24 | 13 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| 1870–1879 | 14 | 6 | 8 | 14 | 6 | 8 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| Unknown | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| Total | 120 | 65 | 55 | 106 | 57 | 49 | 14 | 3 | (?) | 8 | 2 | 2 | 6 | 1 | 1 | 13 | 3 | (?) | 7 | 2 | 2 | 6 | 1 | 1 | 1 | .... | .... | 1 | .... | .... | .... | .... | .... |

TABLE II.—*Non-congenitally deaf pupils recorded as sporadic cases.*

AMERICAN ASYLUM.

| Period of birth. | Grand total. | | | Not recorded to have married. | | | MARRIED. Total. Total. | | | Total. Males. | | | Total. Females. | | | Married to deaf-mutes. Total. | | | Married to deaf-mutes. Males. | | | Married to deaf-mutes. Females. | | | Not recorded to have married deaf-mutes. Total. | | | Not recorded to have married deaf-mutes. Males. | | | Not recorded to have married deaf-mutes. Females. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total. | Males. | Females. | Total. | Males. | Females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. |
| 1760–1769 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1770–1779 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1780–1789 | 1 | | 1 | 1 | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1790–1799 | 8 | 6 | 2 | 3 | 2 | 1 | 5 | | | 4 | | | 1 | | | 2 | | | 2 | | | | | | 3 | | | 2 | | | 1 | | |
| 1800–1809 | 58 | 35 | 23 | 23 | 11 | 12 | 35 | | | 24 | | | 11 | | | 18 | | | 10 | | | 8 | | | 17 | | | 14 | | | 3 | | |
| 1810–1819 | 141 | 78 | 63 | 57 | 31 | 26 | 84 | 3 | | 47 | 3 | 7 | 37 | | | 72 | 3 | | 40 | 3 | 7 | 32 | | | 12 | | | 7 | | | 5 | | |
| 1820–1829 | 110 | 72 | 38 | 54 | 38 | 16 | 56 | 1 | | 34 | 1 | 1 | 22 | | | 43 | 1 | | 26 | 1 | 1 | 17 | | | 13 | | | 8 | | | 5 | | |
| 1830–1839 | 127 | 78 | 49 | 68 | 40 | 28 | 59 | 2 | | 38 | 2 | 5 | 21 | | | 54 | 2 | | 33 | 2 | 5 | 21 | | | 5 | | | 5 | | | | | |
| 1840–1849 | 156 | 96 | 68 | 125 | 77 | 48 | 31 | | | 19 | | | 12 | | | 22 | | | 12 | | | 10 | | | 9 | | | 7 | | | 2 | | |
| 1850–1859 | 194 | 122 | 72 | 182 | 117 | 65 | 12 | | | 5 | | | 7 | | | 8 | | | 3 | | | 5 | | | 4 | | | 2 | | | 2 | | |
| 1860–1869 | 119 | 74 | 45 | 119 | 74 | 45 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Unknown | 1 | 1 | | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total | 915 | 562 | 353 | 633 | 391 | 242 | 282 | 6 | (?) | 171 | 6 | 13 | 111 | | | 219 | 6 | (?) | 126 | 6 | 13 | 93 | | | 63 | | | 45 | | | 18 | | |

TABLE H.—*Non-congenitally deaf pupils recorded as sporadic cases*—Continued.

ILLINOIS INSTITUTION.

| Period of birth. | Grand total. | | | Not recorded to have married. | | | MARRIED. Total. Total. | | | Total. Males. | | | Total. Females. | | | Married to deaf-mutes. Total. | | | Married to deaf-mutes. Males. | | | Married to deaf-mutes. Females. | | | Not recorded to have married deaf-mutes. Total. | | | Not recorded to have married deaf-mutes. Males. | | | Not recorded to have married deaf-mutes. Females. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total. | Males. | Females. | Total. | Males. | Females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. |
| 1810–1819 | 2 | 1 | 1 | 1 | ...... | 1 | 1 | 1 | ...... | 1 | 1 | 1 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 1 | 1 | 1 | 1 | 1 | 1 | ...... | ...... | ...... |
| 1820–1829 | 9 | 2 | 7 | 5 | 1 | 4 | 4 | ...... | ...... | 1 | ...... | ...... | 3 | ...... | ...... | 3 | ...... | ...... | 1 | ...... | ...... | 2 | ...... | ...... | 1 | ...... | ...... | ...... | ...... | ...... | 1 | ...... | ...... |
| 1830–1839 | 52 | 27 | 25 | 37 | 19 | 18 | 15 | 1 | ...... | 8 | ...... | ...... | 7 | 1 | 1 | 13 | 1 | ...... | 6 | ...... | ...... | 7 | 1 | 1 | 2 | ...... | ...... | 2 | ...... | ...... | ...... | ...... | ...... |
| 1840–1849 | 142 | 90 | 52 | 106 | 69 | 37 | 36 | 1 | ...... | 21 | 1 | 2 | 15 | ...... | ...... | 31 | 1 | ...... | 19 | 1 | 2 | 12 | ...... | ...... | 5 | ...... | ...... | 2 | ...... | ...... | 3 | ...... | ...... |
| 1850–1859 | 178 | 103 | 75 | 159 | 94 | 65 | 19 | ...... | ...... | 9 | ...... | ...... | 10 | ...... | ...... | 16 | ...... | ...... | 7 | ...... | ...... | 9 | ...... | ...... | 3 | ...... | ...... | 2 | ...... | ...... | 1 | ...... | ...... |
| 1860–1869 | 327 | 182 | 145 | 321 | 178 | 143 | 6 | ...... | ...... | 4 | ...... | ...... | 2 | ...... | ...... | 6 | ...... | ...... | 4 | ...... | ...... | 2 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
| 1870–1879 | 115 | 63 | 52 | 115 | 63 | 52 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
| Unknown | 2 | 1 | 1 | 2 | 1 | 1 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
| Total | 827 | 469 | 358 | 746 | 425 | 321 | 81 | 3 | (?) | 44 | 2 | 3 | 37 | 1 | 1 | 69 | 2 | (?) | 37 | 1 | 2 | 32 | 1 | 1 | 12 | 1 | 1 | 7 | 1 | 1 | 5 | ...... | ...... |

TABLE I.—*Pupils the cause of whose deafness is not stated who are recorded to have deaf-mute relatives other than children.*

AMERICAN ASYLUM.

| Period of birth. | Grand total. | | | Not recorded to have married. | | | MARRIED. | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Total. | | | | | | | | | Married to deaf-mutes. | | | | | | | | | Not recorded to have married deaf mutes. | | | | | | | | |
| | | | | | | | Total | | | Males. | | | Females. | | | Total. | | | Males. | | | Females. | | | Total. | | | Males. | | | Females. | | |
| | Total. | Males. | Females. | Total. | Males. | Females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. |
| 1760–1769 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1770–1779 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1780–1789 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1790–1799 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1800–1809 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1810–1819 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1820–1829 | 1 | 1 | | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1830–1839 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1840–1849 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1850–1859 | 2 | 1 | 1 | 2 | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1860–1869 | 6 | 3 | 3 | 6 | 3 | 3 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Unknown | 1 | | 1 | 1 | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total | 10 | 5 | 5 | 10 | 5 | 5 | | | | | | | | | | | | | | | | | | | | | | | | | | | |

TABLE I.—*Pupils the cause of whose deafness is not stated who are recorded to have deaf-mute relatives other than children*—Continued.

ILLINOIS INSTITUTION.

| Period of birth. | Grand total. Total. | Grand total. Males. | Grand total. Females. | Not recorded to have married. Total. | Not recorded to have married. Males. | Not recorded to have married. Females. | Married. Total. Total. Total. | Married. Total. Total. Recorded to have deaf children. | Married. Total. Total. Recorded number of deaf children born to the pupils. | Married. Total. Males. Total. | Married. Total. Males. Recorded to have deaf children. | Married. Total. Males. Recorded number of deaf children born to the males. | Married. Total. Females. Total. | Married. Total. Females. Recorded to have deaf children. | Married. Total. Females. Recorded number of deaf children born to the females. | Married. Married to deaf-mutes. Total. Total. | Married. Married to deaf-mutes. Total. Recorded to have deaf children. | Married. Married to deaf-mutes. Total. Recorded number of deaf children born to the pupils. | Married. Married to deaf-mutes. Males. Total. | Married. Married to deaf-mutes. Males. Recorded to have deaf children. | Married. Married to deaf-mutes. Males. Recorded number of deaf children born to the males. | Married. Married to deaf-mutes. Females. Total. | Married. Married to deaf-mutes. Females. Recorded to have deaf children. | Married. Married to deaf-mutes. Females. Recorded number of deaf children born to the females. | Married. Not recorded to have married deaf-mutes. Total. Total. | Married. Not recorded to have married deaf-mutes. Total. Recorded to have deaf children. | Married. Not recorded to have married deaf-mutes. Total. Recorded number of deaf children born to the pupils. | Married. Not recorded to have married deaf-mutes. Males. Total. | Married. Not recorded to have married deaf-mutes. Males. Recorded to have deaf children. | Married. Not recorded to have married deaf-mutes. Males. Recorded number of deaf children born to the males. | Married. Not recorded to have married deaf-mutes. Females. Total. | Married. Not recorded to have married deaf-mutes. Females. Recorded to have deaf children. | Married. Not recorded to have married deaf-mutes. Females. Recorded number of deaf children born to the females. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1810–1819 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1820–1829 | 1 | 1 | | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1830–1839 | 3 | 2 | 1 | 1 | 1 | | 2 | 1 | | 1 | 1 | 2 | 1 | | | 1 | 1 | | 1 | 1 | 2 | | | | 1 | | | | | | 1 | | |
| 1840–1849 | 4 | 2 | 2 | 4 | 2 | 2 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1850–1859 | 13 | 5 | 8 | 13 | 5 | 8 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1860–1869 | 13 | 7 | 6 | 13 | 7 | 6 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1870–1879 | 6 | 3 | 3 | 6 | 3 | 3 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Unknown | 2 | 1 | 1 | 2 | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total | 42 | 21 | 21 | 40 | 20 | 20 | 2 | 1 | (?) | 1 | 1 | 2 | 1 | | | 1 | 1 | (?) | 1 | 1 | 2 | | | | 1 | | | | | | 1 | | |

TABLE J.—*Pupils, the cause of whose deafness is not stated, who are recorded as sporadic cases.*

AMERICAN ASYLUM.

| Period of birth. | Grand total. | | | Not recorded to have married. | | | Married. | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Total. | | | | | | | | | Married to deaf-mutes. | | | | | | | | | Not recorded to have married deaf-mutes. | | | | | | | | |
| | | | | | | | Total. | | | Males. | | | Females. | | | Total. | | | Males. | | | Females. | | | Total | | | Males. | | | Females. | | |
| | Total. | Males. | Females. | Total. | Males. | Females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children | Recorded number of deaf children born to the males | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males. | Total | Recorded to have deaf children | Recorded number of deaf children born to the females. | Total. | Recorded to have deaf children | Recorded number of deaf children born to the pupils. | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the males | Total. | Recorded to have deaf children. | Recorded number of deaf children born to the females |
| 1760–1769 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1770–1779 | 1 | 1 | | | | | 1 | | | 1 | | | | | | | | | | | | | | | 1 | | | 1 | | | | | |
| 1780–1789 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1790–1799 | 5 | 3 | 2 | 3 | 1 | 2 | 2 | | | 2 | | | | | | | | | | | | | | | 2 | | | 2 | | | | | |
| 1800–1809 | 15 | 10 | 5 | 8 | 5 | 3 | 7 | | | 5 | | | 2 | | | 4 | | | 4 | | | | | | 3 | | | 1 | | | 2 | | |
| 1810–1819 | 15 | 9 | 6 | 9 | 6 | 3 | 6 | | | 3 | | | 3 | | | 4 | | | 2 | | | 2 | | | 2 | | | 1 | | | 1 | | |
| 1820–1829 | 10 | 7 | 3 | 6 | 4 | 2 | 4 | | | 3 | | | 1 | | | 3 | | | 2 | | | 1 | | | 1 | | | 1 | | | | | |
| 1830–1839 | 5 | 4 | 1 | 4 | 4 | | 1 | 1 | | | | | 1 | 1 | 1 | 1 | 1 | | | | | 1 | 1 | 1 | | | | | | | | | |
| 1840–1849 | 7 | 3 | 4 | 6 | 3 | 3 | 1 | | | | | | 1 | | | 1 | | | | | | 1 | | | | | | | | | | | |
| 1850–1859 | 17 | 7 | 10 | 14 | 6 | 8 | 3 | | | 1 | | | 2 | | | 1 | | | | | | 1 | | | 2 | | | 1 | | | 1 | | |
| 1860–1869 | 6 | 6 | | 6 | 6 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Unknown | 2 | 2 | | 2 | 2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total | 83 | 52 | 31 | 58 | 37 | 21 | 25 | 1 | (b) | 15 | | | 10 | 1 | 1 | 14 | 1 | (b) | 8 | | | 6 | 1 | 1 | 11 | | | 7 | | | 4 | | |

TABLE J.—*Pupils the cause of whose deafness is not stated, who are recorded as sporadic cases*—Continued.

ILLINOIS INSTITUTION.

| Period of birth. | Grand total. Total. | Grand total. Males. | Grand total. Females. | Not recorded to have married. Total. | Not recorded to have married. Males. | Not recorded to have married. Females. | Married. Total. Total. Total. | Married. Total. Total. Recorded to have deaf children. | Married. Total. Total. Recorded number of deaf children born to the pupils. | Married. Total. Males. Total. | Married. Total. Males. Recorded to have deaf children. | Married. Total. Males. Recorded number of deaf children born to the males. | Married. Total. Females. Total. | Married. Total. Females. Recorded to have deaf children. | Married. Total. Females. Recorded number of deaf children born to the females. | Married to deaf mutes. Total. Total. | Married to deaf mutes. Total. Recorded to have deaf children. | Married to deaf mutes. Total. Recorded number of deaf children born to the pupils. | Married to deaf mutes. Males. Total. | Married to deaf mutes. Males. Recorded to have deaf children. | Married to deaf mutes. Males. Recorded number of deaf children born to the males. | Married to deaf mutes. Females. Total. | Married to deaf mutes. Females. Recorded to have deaf children. | Married to deaf mutes. Females. Recorded number of deaf children born to the females. | Not recorded to have married deaf-mutes. Total. Total. | Not recorded to have married deaf-mutes. Total. Recorded to have deaf children. | Not recorded to have married deaf-mutes. Total. Recorded number of deaf children born to the pupils. | Not recorded to have married deaf-mutes. Males. Total. | Not recorded to have married deaf-mutes. Males. Recorded to have deaf children. | Not recorded to have married deaf-mutes. Males. Recorded number of deaf children born to the males. | Not recorded to have married deaf-mutes. Females. Total. | Not recorded to have married deaf-mutes. Females. Recorded to have deaf children. | Not recorded to have married deaf-mutes. Females. Recorded number of deaf children born to the females. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1810–1819... | 2 | | 2 | 1 | | 1 | 1 | | | | | | 1 | | | 1 | | | | | | 1 | | | | | | | | | | | |
| 1820–1829 ... | 2 | 1 | 1 | 1 | | 1 | 1 | 1 | | 1 | 1 | 1 | | | | 1 | 1 | | 1 | 1 | 1 | | | | | | | | | | | | |
| 1830–1839.... | 14 | 9 | 5 | 14 | 9 | 5 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1840–1849 ... | 23 | 14 | 9 | 20 | 13 | 7 | 3 | | | 1 | | | 2 | | | 2 | | | 1 | | | 1 | | | 1 | | | | | | 1 | | |
| 1850–1859 ... | 44 | 20 | 24 | 41 | 18 | 23 | 3 | | | 2 | | | 1 | | | 2 | | | 2 | | | | | | 1 | | | | | | 1 | | |
| 1860–1869.... | 91 | 54 | 37 | 86 | 53 | 33 | 5 | | | 1 | | | 4 | | | 4 | | | 1 | | | 3 | | | 1 | | | | | | 1 | | |
| 1870–1879.... | 37 | 23 | 14 | 37 | 23 | 14 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Unknown.. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total ... | 213 | 121 | 92 | 200 | 116 | 84 | 13 | 1 | (?) | 5 | 1 | 1 | 8 | | | 10 | 1 | (?) | 5 | 1 | 1 | 5 | | | 3 | | | | | | 3 | | |

TABLE K.—*Non-congenital pupils.*

| Period. | American Asylum. | | Illinois Institution. | |
|---|---|---|---|---|
| | Classified according to period of birth. | Classified according to period when hearing was lost. | Classified according to period of birth. | Classified according to period when hearing as lost. |
| 1760–1769 | ........ | ........ | ........ | ........ |
| 1770–1779 | ........ | ........ | ........ | ........ |
| 1780–1789 | 1 | 1 | ........ | ........ |
| 1790–1799 | 12 | 10 | ........ | ........ |
| 1800–1809 | 70 | 42 | ........ | ........ |
| 1810–1819 | 147 | 151 | 2 | 1 |
| 1820–1829 | 121 | 112 | 11 | 5 |
| 1830–1839 | 146 | 138 | 58 | 21 |
| 1840–1849 | 182 | 167 | 164 | 116 |
| 1850–1859 | 224 | 196 | 217 | 133 |
| 1860–1869 | 133 | 168 | 364 | 224 |
| 1870–1879 | ........ | 17 | 129 | 120 |
| Unknown | 1 | 38 | 2 | 327 |
| Total | 1,040 | 1,040 | 947 | 947 |

TABLE L.—*Non-congenital pupils of the American Asylum, classified according to the period when hearing was lost and according to the disease that caused deafness.*

| Cause of deafness. | 1780–1789. | 1790–1799. | 1800–1809. | 1810–1819. | 1820–1829. | 1830–1839. | 1840–1849. | 1850–1859. | 1860–1869. | 1870–1879. | Total. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Scarlet fever[1] | ...... | 1 | 5 | 8 | 13 | 61 | 72 | 84 | 62 | 5 | 311 |
| Brain fever[2] | ...... | ...... | ...... | 4 | 15 | 7 | 21 | 12 | 14 | 2 | 75 |
| Epidemic cerebro-spinal meningitis[3] | ...... | ...... | 8 | 35 | 1 | ...... | 1 | ...... | 4 | 2 | 54 |
| Measles | ...... | 1 | ...... | 7 | 1 | 6 | 10 | 8 | 2 | ...... | 38 |
| Whooping-cough | ...... | ...... | 2 | 2 | 6 | 1 | 5 | 6 | 4 | ...... | 29 |
| Hydrocephalus[4] | ...... | ...... | ...... | 3 | 3 | 6 | 1 | 3 | 2 | 1 | 19 |
| Typhus fever | ...... | ...... | 3 | 4 | 1 | 1 | 2 | 2 | 1 | ...... | 17 |
| Convulsions[5] | ...... | ...... | ...... | 2 | . | 3 | 3 | 1 | 4 | 1 | 17 |
| Disease of ear[6] | ...... | ...... | 2 | 12 | 21 | 22 | 23 | 28 | 13 | ...... | 124 |
| Diseases of lungs and air passages[7] | ...... | ...... | ...... | 1 | 1 | 2 | 6 | 6 | 14 | ...... | 30 |
| Miscellaneous diseases[8] | ...... | 1 | 2 | 4 | ...... | 6 | 7 | 11 | 13 | 5 | 49 |
| Accident[9] | ...... | 1 | 1 | 5 | 3 | 9 | 5 | 15 | 13 | 1 | 53 |
| Diseases not specified | 1 | 6 | 19 | 64 | 35 | 11 | 11 | 17 | 22 | ...... | 186 |
| Total | 1 | 10 | 42 | 151 | 112 | 138 | 167 | 196 | 168 | 17 | 1,002 |
| Period when hearing was lost unknown | | | | | | | | | | | 38 |
| Total | | | | | | | | | | | 1,040 |

[1] Includes canker-rash (15 cases). [2] Includes inflammation of brain, inflammation of head. [3] Includes spotted fever (51 cases), meningitis (3 cases). [4] Includes dropsy in head, dropsy in brain, water on brain. [5] Includes fits, paralytic fit (1 case), paralysis and convulsions (1 case). [6] Includes disease in head, humor in head, abscess in head, eruption in head, gathering in head, scrofula in head, sores in head, ulcers in head, ulcers in ears, sores in ears, discharge from ears, gathering in ears. [7] Includes lung fever (11 cases), cold (18 cases), influenza (1 case). [8] Includes small-pox, chicken-pox, diptheria, croup, bilious fever, catarrhal fever, erysipelas, palsy, salt rheum, mumps, spasmodic cough, marasmus, rickets, teething, cholera infantum, inflammation of bowels. [9] Includes fall (39 cases), discharge of cannon, pistol shot, scald (2 cases), fright (2 cases), blow on head, run over by cart, sea bathing.

TABLE M.—*Non-congenital pupils of the Illinois Institution, classified according to the period when hearing was lost and according to the disease that caused deafness.*

| Cause of deafness. | 1810–1819. | 1820–1829. | 1830–1839. | 1840–1849. | 1850–1859. | 1860–1869. | 1870–1879. | Unknown. | Total. |
|---|---|---|---|---|---|---|---|---|---|
| Spotted fever [a] | ...... | ...... | ...... | ...... | 2 | 27 | 12 | 7 | 48 |
| Meningitis [b] | 1 | ...... | ...... | ...... | ...... | 6 | 29 | 143 | 179 |
| Scarlet fever | ...... | ...... | 6 | 18 | 22 | 28 | 9 | 27 | 110 |
| Brain fever | ...... | ...... | ...... | 6 | 9 | 31 | 17 | 10 | 73 |
| Inflammation of brain | ...... | ...... | ...... | 5 | 2 | 4 | 2 | 12 | 25 |
| Congestion of brain | ...... | ...... | ...... | 1 | 2 | 3 | ...... | 5 | 11 |
| Disease of ear [1] | ...... | 1 | 1 | 7 | 8 | 15 | 3 | 28 | 63 |
| Diseases of lungs and air passages [2] | ...... | 1 | 1 | 7 | 6 | 6 | 12 | 17 | 50 |
| Accident [3] | ...... | 1 | 1 | 6 | 9 | 11 | 5 | 7 | 40 |
| Measles | ...... | ...... | ...... | 4 | 6 | 8 | 8 | 11 | 37 |
| Typhoid fever | ...... | 1 | ...... | 3 | 8 | 14 | 6 | 5 | 37 |
| Whooping-cough | ...... | ...... | 2 | 4 | 2 | 3 | 1 | 8 | 20 |
| Convulsions [4] | ...... | ...... | ...... | 5 | 2 | 6 | 1 | 3 | 17 |
| Quinine | ...... | ...... | 1 | 1 | 6 | 3 | ...... | 3 | 14 |
| Hydrocephalus | ...... | ...... | 2 | 2 | 4 | 2 | ...... | ...... | 10 |
| Diphtheria | ...... | ...... | ...... | ...... | 1 | 4 | 1 | 4 | 10 |
| Miscellaneous diseases [5] | ...... | ...... | 1 | 24 | 14 | 17 | 6 | 19 | 81 |
| Diseases not specified | ...... | 1 | 6 | 23 | 30 | 36 | 8 | 18 | 122 |
| Total | 1 | 5 | 21 | 116 | 133 | 224 | 120 | 327 | 947 |

[a] Epidemic cerebro-spinal meningitis.

[1] Includes gathering in head (3 cases), scrofula (10 cases), gathering in ears, sore ears, earache, rising in head, risings, swelling in head, gradual loss, inflammation of head, sickness in head.

[2] Includes cold (31 cases), lung fever, pneumonia, bronchial affection, influenza, catarrh (5 cases).

[3] Includes shock of lightning, sunstroke, exposure to heat, fell into water, sea-sickness, burn, scald, sprain in neck, tar cap for scald-head, washing in cold spring, fright (2 cases), fall (22 cases), drinking lye (1 case).

[4] Includes spasms and fits.

[5] Includes mumps (7 cases), bilious fever (9 cases), nervous fever (6 cases), congestive chill (7 cases), winter fever (8 cases), remittent ever (3 cases), teething, jaundice, pernicious fever, worms and fever, ague, paralysis, vaccination, small-pox, chicken-pox, cholera, croup, cramps, chills, cold plague, worm fever, typhus fever, cholera infantum, inflammation of bowels, disease of kidney, cancer, rickets, erysipelas, spinal disease (6 cases).

TABLE N.—*Analysis of 22,472 cases of deaf-mutes from the census returns, showing the number of these deaf-mutes living June 1, 1880, who became deaf each year since the year 1770.*

| Year. | No. | Year. | No. | Year. | No. | Year. | No. |
|---|---|---|---|---|---|---|---|
| 1879–'80 | ........ | 1869–'70 | 751 | 1859–'60 | 527 | 1849–'50 | 453 |
| 1878–'79 | 161 | 1868–'69 | 665 | 1858–'59 | 436 | 1848–'49 | 219 |
| 1877–'78 | 207 | 1867–'68 | 721 | 1857–'58 | 484 | 1847–'48 | 264 |
| 1876–'77 | 300 | 1866–'67 | 710 | 1856–'57 | 402 | 1846–'47 | 221 |
| 1875–'76 | 414 | 1865–'66 | 794 | 1855–'56 | 422 | 1845–'46 | 230 |
| 1874–'75 | 472 | 1864–'65 | 797 | 1854–'55 | 349 | 1844–'45 | 308 |
| 1873–'74 | 750 | 1863–'64 | 776 | 1853–'54 | 382 | 1843–'44 | 237 |
| 1872–'73 | 1,168 | 1862–'63 | 692 | 1852–'53 | 303 | 1842–'43 | 209 |
| 1871–'72 | 1,067 | 1861–'62 | 642 | 1851–'52 | 349 | 1841–'42 | 215 |
| 1870–'71 | 769 | 1860–'61 | 470 | 1850–'51 | 260 | 1840–'41 | 153 |
| Ten years | 5,308 | ........ | 7,018 | ........ | 3,914 | ........ | 2,509 |
| 1839–'40 | 318 | 1829–'30 | 200 | 1819–'20 | 147 | 1809–'10 | 81 |
| 1838–'39 | 139 | 1828–'29 | 93 | 1818–'19 | 54 | 1808–'09 | 36 |
| 1837–'38 | 158 | 1827–'28 | 111 | 1817–'18 | 73 | 1807–'08 | 46 |
| 1836–'37 | 135 | 1826–'27 | 95 | 1816–'17 | 77 | 1806–'07 | 15 |
| 1835–'36 | 125 | 1825–'26 | 95 | 1815–'16 | 73 | 1805–'06 | 27 |
| 1834–'35 | 188 | 1824–'25 | 120 | 1814–'15 | 83 | 1804–'05 | 37 |
| 1833–'34 | 141 | 1823–'24 | 88 | 1813–'14 | 49 | 1803–'04 | 23 |
| 1832–'33 | 126 | 1822–'23 | 89 | 1812–'13 | 45 | 1802–'03 | 11 |
| 1831–'32 | 157 | 1821–'22 | 100 | 1811–'12 | 55 | 1801–'02 | 11 |
| 1830–'31 | 105 | 1820–'21 | 67 | 1810–'11 | 43 | 1800–'01 | 7 |
| Ten years | 1,592 | ........ | 1,058 | ........ | 699 | ........ | 294 |
| 1799–1800 | 23 | 1789–'90 | 3 | 1779–'80 | ........ | ........ | ........ |
| 1798–'99 | 10 | 1788–'89 | ........ | 1778–'79 | ........ | ........ | ........ |
| 1797–'98 | 11 | 1787–'88 | 2 | 1777–'78 | ........ | ........ | ........ |
| 1796–'97 | 6 | 1786–'87 | ........ | 1776–'77 | ........ | ........ | ........ |
| 1795–'96 | 4 | 1785–'86 | ........ | 1775–'76 | ........ | ........ | ........ |
| 1794–'95 | 4 | 1784–'85 | 4 | 1774–'75 | ........ | ........ | ........ |
| 1793–'94 | 8 | 1783–'84 | ........ | 1773–'74 | ........ | ........ | ........ |
| 1792–'93 | 1 | 1782–'83 | ........ | 1772–'73 | ........ | ........ | ........ |
| 1791–'92 | 3 | 1781–'82 | ........ | 1771–'72 | ........ | ........ | ........ |
| 1790–'91 | 1 | 1780–'81 | ........ | 1770–'71 | 1 | ........ | ........ |
| Ten years | 71 | ........ | 9 | ........ | 1 | ........ | ........ |

TABLE O.—*Analysis of 22,472 cases of deaf-mutes from the census returns.*

[This table shows that the decline in the number of these deaf-mutes returned who became deaf since 1873 affects the congenital, as well as the non-congenitally deaf.]

| Year in which deafness occurred. | 1873. | 1874. | 1875. | 1876. | 1877. | 1878. | 1879. |
|---|---|---|---|---|---|---|---|
| Total number | 1,168 | 750 | 472 | 414 | 300 | 207 | 161 |
| Congenitally deaf | 348 | 271 | 203 | 202 | 130 | 105 | 46 |
| Non-congenitally deaf | 820 | 479 | 269 | 212 | 170 | 102 | 115 |

TABLE P.—*Analysis of 22,472 cases of deaf-mutes taken from census returns, classified by periods of five years.*

[The number who became deaf in each quinquennial period is reduced to a percentage of the whole on a basis of 10,000 cases in all.]

| Period. | Number. | Per cent. | Period. | Number. | Per cent. |
|---|---|---|---|---|---|
| 1781–1785 | 4 | .0002 | 1831–1835 | 717 | .0319 |
| 1786–1790 | 5 | .0002 | 1836–1840 | 875 | .0389 |
| 1791–1795 | 17 | .0008 | 1841–1845 | 1122 | .0499 |
| 1796–1800 | 54 | .0024 | 1846–1850 | 1387 | .0617 |
| 1801–1805 | 89 | .0040 | 1851–1855 | 1643 | .0731 |
| 1806–1810 | 205 | .0091 | 1856–1860 | 2271 | .1011 |
| 1811–1815 | 275 | .0122 | 1861–1865 | 3377 | .1503 |
| 1816–1820 | 424 | .0189 | 1866–1870 | 3641 | .1620 |
| 1821–1825 | 464 | .0206 | 1871–1875 | 4226 | .1881 |
| 1826–1830 | 594 | .0265 | 1876–1880 | 1082 | .0481 |

TABLE Q.—*Analysis of 22,472 cases from the census returns, classified by periods of five years, and separating the congenital from the non-congenital cases.*

| Period. | Congenital. | Non-congenital. | Total. |
|---|---|---|---|
| 1781–1785 | 4 | 0 | 4 |
| 1786–1790 | 5 | 0 | 5 |
| 1791–1795 | 15 | 2 | 17 |
| 1796–1800 | 48 | 6 | 54 |
| 1801–1805 | 79 | 10 | 89 |
| 1806–1810 | 162 | 43 | 205 |
| 1811–1815 | 193 | 82 | 275 |
| 1816–1820 | 279 | 145 | 424 |
| 1821–1825 | 328 | 136 | 464 |
| 1826–1830 | 423 | 171 | 594 |
| 1831–1835 | 477 | 240 | 717 |
| 1836–1840 | 601 | 274 | 875 |
| 1841–1845 | 719 | 403 | 1,122 |
| 1846–1850 | 895 | 492 | 1,387 |
| 1851–1855 | 998 | 645 | 1,643 |
| 1856–1860 | 1,462 | 809 | 2,271 |
| 1861–1865 | 1,639 | 1,738 | 3,377 |
| 1866–1870 | 1,759 | 1,882 | 3,641 |
| 1871–1875 | 1,585 | 2,641 | 4,226 |
| 1876–1880 | 483 | 599 | 1,082 |
| Total | 12,154 | 10,318 | 22,472 |

TABLE R.—*Total number of deaf-mutes in the United States living June* 1, 1880, *classified according to race and sex.*

| Causes of deafness. | Colored. | | Foreign white. | | Native white. | | Total. | |
|---|---|---|---|---|---|---|---|---|
| | Males. | Females. | Males. | Females. | Males. | Females. | Males. | Females. |
| Congenital | 714 | 587 | 545 | 444 | 5,229 | 4,520 | 6,488 | 5,551 |
| Injur to ear | 7 | 2 | 8 | 2 | 34 | 17 | 49 | 21 |
| Disease of ear | 7 | 8 | 10 | 7 | 204 | 166 | 221 | 181 |
| Other diseases | 178 | 147 | 306 | 252 | 4,172 | 3,368 | 4,656 | 3,767 |
| Miscellaneous | 73 | 28 | 81 | 77 | 610 | 423 | 764 | 52[illegible] |
| Not stated | 815 | 651 | 944 | 681 | 4,630 | 3,931 | 6,389 | 5,263 |
| Total | 1,794 | 1,423 | 1,894 | 1,463 | 14,879 | 12,425 | 18,567 | 15,311 |

TABLE S.—*Institutions for the deaf and dumb in the United States*, 1883.

A.—PUBLIC INSTITUTIONS.

| | Name. | Location. | Date of opening. | Number of pupils. During the year 1883. | Male. | Female. | Present December 1, 1883. | Total number of pupils who have received instruction. | Admitted since the opening of the institution. Number of pupils having one parent deaf. | Number of pupils having both parents deaf. | Total number having one or both parents deaf. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | American Asylum | Hartford, Conn | 1817 | 210 | 126 | 84 | 174 | 2,325 | 23 | 35 | 58 |
| 2 | New York Institution | Washington H'ts, New York, N. Y. | 1818 | 488 | 310 | 178 | 369 | 2,993 | 31 | 22 | 53 |
| 3 | Pennsylvania Institution | Philadelphia, Pa | 1820 | 362 | 206 | 156 | 298 | 2,079 | 2 | 19 | 21 |
| 4 | Kentucky Institution | Danville, Ky | 1823 | 167 | 98 | 69 | 136 | 830 | ..... | ..... | ..... |
| 5 | Ohio Institution | Columbus, Ohio | 1829 | 505 | 274 | 231 | 407 | 2,008 | 2 | 11 | 13 |
| 6 | Virginia Institution | Staunton, Va | 1839 | 80 | 44 | 36 | 74 | 546 | ..... | ..... | ..... |
| 7 | Indiana Institution | Indianapolis, Ind | 1844 | 328 | 175 | 153 | 312 | 1,495 | ..... | ..... | ..... |
| 8 | Tennessee School | Knoxville, Tenn | 1845 | 147 | 90 | 57 | 118 | ..... | ..... | ..... | ..... |
| 9 | North Carolina Institution | Raleigh, N. C | 1844 | 111 | 56 | 48 | 101 | ..... | ..... | ..... | ..... |
| 10 | Illinois Institution | Jacksonville, Ill | 1846 | 575 | 325 | 250 | 501 | 1,700 | 5 | 9 | 14 |
| 11 | Georgia Institution | Cave Spring, Ga | 1846 | 93 | 53 | 40 | 85 | 325 | ..... | ..... | ..... |
| 12 | South Carolina Institution | Cedar Spring, S. C | 1849 | 58 | 26 | 32 | 48 | 185 | 0 | 6 | 6 |
| 13 | Missouri Institution | Fulton, Mo | 1851 | 250 | 152 | 98 | 199 | 835 | 3 | 0 | 3 |
| 14 | Louisiana Institution | Baton Rouge, La | 1852 | 43 | 25 | 18 | 38 | ..... | 0 | 3 | 3 |
| 15 | Wisconsin Institution | Delavan, Wis | 1852 | 237 | 134 | 103 | 208 | 665 | 3 | 1 | 4 |
| 16 | Michigan Institution | Flint, Mich | 1854 | 271 | 145 | 126 | 266 | 948 | ..... | ..... | ..... |
| 17 | Iowa Institution | Council Bluffs, Iowa | 1855 | 290 | 170 | 120 | 260 | 657 | ..... | ..... | ..... |
| 18 | Mississippi Institution | Jackson, Miss | 1856 | 78 | 35 | 43 | 76 | ..... | ..... | ..... | ..... |
| 19 | Texas Asylum | Austin, Tex | 1857 | 97 | 65 | 32 | 86 | 203 | ..... | ..... | ..... |
| 20 | Columbia Institution | Washington, D. C | 1857 | 100 | 83 | 17 | 88 | 489 | 1 | 8 | 9 |
| 21 | Alabama Institution | Talladega, Ala | 1860 | 51 | 30 | 21 | 51 | 185 | 0 | 0 | 0 |
| 22 | California Institution | Berkeley, Cal | 1860 | 126 | 80 | 46 | 121 | 262 | 1 | 0 | 1 |
| 23 | Kansas Institution | Olathe, Kansas | 1861 | 190 | 102 | 88 | 157 | 369 | ..... | ..... | ..... |
| 24 | Le Couteulx St. Mary's Institution. | Buffalo, N. Y | 1862 | 167 | 94 | 73 | 154 | 350 | 0 | 1 | 1 |
| 25 | Minnesota School | Faribault, Minn | 1863 | 147 | 82 | 65 | 129 | 330 | 4 | 1 | 5 |
| 26 | Institution for Improved Instruction. | New York, N. Y | 1867 | 187 | 108 | 79 | 161 | 311 | 0 | 0 | 0 |
| 27 | Clarke Institution | Northampton, Mass. | 1867 | 94 | 49 | 45 | 91 | 220 | 2 | 1 | 3 |
| 28 | Arkansas Institute | Little Rock, Ark | 1868 | 80 | 47 | 33 | 52 | 195 | ..... | ..... | ..... |
| 29 | Maryland School | Frederick City, Md. | 1868 | 108 | 60 | 48 | 99 | 278 | 0 | 5 | 5 |
| 30 | Nebraska Institute | Omaha, Nebr | 1869 | 115 | 74 | 41 | 93 | 181 | ..... | ..... | ..... |
| 31 | Horace Mann School | Boston, Mass | 1869 | 91 | 41 | 50 | 80 | 212 | 0 | 1 | 1 |
| 32 | St. Joseph's Institute | Fordham, N. Y | 1869 | 279 | 125 | 154 | 237 | 333 | ..... | ..... | ..... |
| 33 | West Virginia Institution | Romney, W. Va | 1870 | 71 | 41 | 30 | 60 | 199 | 0 | 2 | 2 |
| 34 | Oregon School | Salem, Oregon | 1870 | 33 | 16 | 17 | 20 | 72 | 0 | 0 | 0 |
| 35 | Institution for Colored | Baltimore, Md | 1872 | 15 | 8 | 7 | 13 | 39 | ..... | ..... | ..... |
| 36 | Colorado Institute | Colorado Sp's, Colo. | 1874 | 49 | 19 | 30 | 43 | 70 | 1 | 0 | 1 |
| 37 | Erie Day-School | Erie, Pa | 1874 | 12 | 9 | 3 | 10 | ..... | 0 | 0 | 0 |
| 38 | Chicago Day-School | Chicago, Ill | 1875 | 58 | 30 | 28 | 48 | 125 | 0 | 0 | 0 |
| 39 | Central New York Institution. | Rome, N. Y | 1875 | 180 | 111 | 69 | 153 | 243 | ..... | ..... | ..... |
| 40 | Cincinnati Day-School | Cincinnati, Ohio | 1875 | 35 | 21 | 14 | 28 | 82 | 0 | 0 | 0 |
| 41 | Western Pennsylvania Institution. | Turtle Creek, Pa | 1876 | 120 | 79 | 41 | 102 | 184 | ..... | ..... | ..... |
| 42 | Western New York Institution. | Rochester, N. Y | 1876 | 162 | 81 | 81 | 143 | 219 | 3 | 2 | 5 |
| 43 | Portland Day-School | Portland, Me | 1876 | 35 | 17 | 18 | 35 | 37 | 0 | 0 | 0 |
| 44 | Rhode Island School | Providence, R. I | 1877 | 33 | 16 | 17 | 25 | 45 | 0 | 0 | 0 |
| 45 | Saint Louis Day-School | Saint Louis, Mo | 1878 | 49 | 32 | 17 | 42 | 73 | 0 | 0 | 0 |
| 46 | New England Industrial School. | Beverly, Mass | 1880 | 19 | 11 | 8 | 19 | 30 | 1 | 5 | 6 |
| 47 | Dakota School | Sioux Falls, D. T | 1880 | 23 | 14 | 9 | 21 | 28 | 0 | 0 | 0 |
| 48 | Oral Branch Pennsylvania Institution. | Philadelphia, Pa | 1881 | 73 | 45 | 28 | 66 | 73 | 1 | 0 | 1 |
| 49 | Scranton Oral School | Scranton, Pa | 1883 | 14 | 7 | 7 | 12 | 14 | ..... | ..... | ..... |
| 50 | New Jersey Institution | Trenton, N. J | 1883 | 82 | 47 | 35 | 81 | 82 | ..... | ..... | ..... |
| 50 | Public institutions | | ..... | 6,991 | 3,898 | 3,093 | 5,993 | 23,119 | 83 | 132 | 215 |

TABLE S.—*Institutions for the deaf and dumb in the United States*, 1883—Continued.

B.—DENOMINATIONAL AND PRIVATE INSTITUTIONS.

| | Name. | Location. | Date of opening. | Number of pupils. During the year 1883. | Male. | Female. | Present December 1, 1883. | Total number of pupils who have received instruction. | Admitted since the opening of the institution. Number of pupils having one parent deaf. | Number of pupils aving both parents deaf. | Total number having one or both parents deaf. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 51 | Whipple's Home School .... | Mystic River, Conn. | 1869 | 16 | 14 | 2 | 10 | 51 | ...... | ...... | ...... |
| 52 | German Evangelical Lutheran Institution. | Norris, Mich ....... | 1875 | 44 | 28 | 16 | 44 | 100 | 0 | 0 | 0 |
| 53 | St. John's Catholic Institute | Saint Francis, Wis . | 1876 | 48 | 30 | 18 | 43 | 127 | 0 | 0 | 0 |
| 54 | F. Knapp's Institute .. .... | Baltimore, Md ..... | 1877 | 34 | 23 | 11 | 30 | 50 | ...... | ...... | ...... |
| 55 | Phonological School ....... | Milwaukee, Wis.... | 1878 | 8 | 5 | 3 | 8 | 50 | ...... | ...... | ...... |
| 56 | St. Joseph's Institute....... | Hannibal, Mo ...... | 1882 | 18 | 7 | 11 | 17 | 18 | 0 | 0 | 0 |
| 57 | A. Graham Bell's School.... | Washington, D. C.. | 1883 | 2 | 1 | 1 | 2 | 2 | 0 | 0 | 0 |
| 58 | Voice and Hearing School.. | Chicago, Ill ........ | 1883 | 8 | 7 | 1 | 8 | 8 | ...... | ...... | ...... |
| 8 | Denominational and private institutions. | ...... | ...... | 178 | 115 | 63 | 162 | 406 | 0 | 0 | 0 |
| 58 | Institutions in the U. S..... | ...... | ...... | 7,169 | 4,013 | 3,156 | 6,155 | 23,525 | 83 | 132 | †215 |
| | National College* .......... | Washington, D. C .. | 1864 | 45 | 45 | 0 | 34 | 252 | | | |

* The National Deaf-Mute College is a distinct organization within the Columbia Institution. Its officers and students are included in the statement of the Columbia Institution given above.

† Eliminating cases where same pupil is returned from more than one institution; 83 have one parent deaf; 124 have both parents deaf; total, 207.

TABLE T.—*Deaf-mute offspring of deaf-mute parents.**

[Analysis of 215 cases received into American Institutions for the Deaf and Dumb before November, 1883.]

| Period of birth. | Deaf-mutes who have one parent deaf. | Deaf-mutes who have both parents deaf. | Total. | Period of birth. | Deaf-mutes who have one parent deaf. | Deaf-mutes who have both parents deaf. | Total. |
|---|---|---|---|---|---|---|---|
| 1771–1780 ............ | ............ | ............ | ........ | 1841–1850 ............ | 18 | 20 | 38 |
| 1781–1790 ............ | ............ | ............ | ........ | 1851–1860 ............ | 25 | 42 | 67 |
| 1791–1800 ............ | ............ | ............ | ........ | 1861–1870 ............ | 14 | 41 | 55 |
| 1801–1810 ............ | 1 | ............ | 1 | 1871–1880 ............ | 6 | 19 | 25 |
| 1811–1820 ............ | 3 | ............ | 3 | | | | |
| 1821–1830 ............ | 6 | ............ | 6 | Total ............ | 82 | 133 | 215 |
| 1831–1840 ............ | 9 | 11 | 20 | | | | |

* A slight error has been discovered in the table owing to duplicate returns in 8 cases. The general result, however, is not affected. The correct figures for deaf-mutes having both parents deaf (reading down the column) should be 11, 20, 36, 37, 20; total, 124.

TABLE U.—*Deaf-mute population compared with the population at large.*

| Period of birth. | Population of the United States (1880), classified according to period of birth, and the number of persons born in each period reduced to a percentage of the whole. | | 12,154 congenital deaf-mutes living June 1, 1880, classified according to period of birth, and the number of deaf-mutes born in each period reduced to a percentage of the whole. | | Deaf-mutes both of whose parents were deaf-mutes, classified according to period of birth, and the number of deaf-mutes born in each period reduced to a percentage of the whole. | |
|---|---|---|---|---|---|---|
| | Number of persons. | Percentage. | Congenital deaf-mutes. | Percentage. | Deaf-mutes both of whose parents were deaf and dumb. | Percentage. |
| 1871–1880 | 13,394,176 | 26.7051 | 2,068 | 17.015 | 19 | 14.3 |
| 1861–1870 | 10,726,601 | 21.3866 | 3,398 | 27.958 | 41 | 30.8 |
| 1851–1860 | 9,168,393 | 18.2798 | 2,460 | 20.240 | 42 | 31.6 |
| 1841–1850 | 6,369,362 | 12.6992 | 1,611 | 13.280 | 20 | 15.0 |
| 1831–1840 | 4,558,256 | 9.0882 | 1,078 | 8.870 | 11 | 8.3 |
| 1821–1830 | 3,111,317 | 6.2033 | 751 | 6.179 | | |
| 1811–1820 | 1,830,095 | 3.6488 | 472 | 3.883 | | |
| 1801–1810 | 776,507 | 1.5482 | 241 | 1.983 | | |
| 1791–1800 | 196,197 | 0.3912 | 63 | 0.518 | | |
| 1781–1790 | 20,863 | 0.0416 | 9 | 0.074 | | |
| ——1780 | 1,016 | 0.0080 | | | | |
| Total | 50,155,783 | 100.0000 | 12,154 | 100.000 | 133 | 100.0 |

TABLE V.—*Tabular statement of the institutions of the world for the education of the deaf and dumb.*

| Country. | No. of institutions. | NUMBER OF PUPILS. Total. | Male. | Female. | No. of teachers. | METHODS OF INSTRUCTION. Manual. No. of institutions. | No. of pupils. | No. of teachers. | Oral. No. of institutions. | No. of pupils. | No. of teachers. | Combined. No. of institutions. | No. of pupils. | No. of teachers. | Not reported. No. of institutions. | No. of pupils. | No. of teachers. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Australia | 3 | 147 | 82 | 65 | 11 | 1 | 14 | 2 | | | | | | | 2 | 133 | 9 |
| Austria-Hungary | 17 | 1,147 | 656 | 454 | 64 | | | | 17 | 1,147 | 64 | | | | | | |
| Belgium | 10 | 864 | 482 | 382 | | | | | 5 | 339 | | 5 | 525 | | | | |
| Brazil | 1 | 32 | 32 | | 3 | | | | | | | | | | 1 | 32 | 3 |
| Canada | 7 | 803 | 397 | 406 | 84 | 1 | | | 1 | 150 | 27 | 5 | 653 | 57 | | | |
| Denmark | 4 | 326 | 150 | 176 | 41 | 1 | 142 | 15 | 2 | 150 | 23 | | | | 1 | 34 | 3 |
| France | 67 | 3,482 | | | | 4 | 254 | | 28 | 1,962 | | 17 | 871 | | 18 | 395 | |
| Germany | 90 | 5,608 | 1,042 | 908 | 580 | | | | 90 | 5,608 | 580 | | | | | | |
| Great Britain and Ireland | 46 | 2,650 | 1,413 | 1,237 | 244 | 8 | 558 | 54 | 20 | 496 | 56 | 13 | 1,356 | 109 | 7 | 249 | 25 |
| Italy | 35 | 1,491 | 815 | 676 | 237 | | | | 34 | 1,405 | 227 | 1 | 86 | 10 | | | |
| Japan | 2 | 65 | 37 | 28 | 7 | 2 | 65 | 7 | | | | | | | | | |
| Luxembourg | 1 | 29 | 15 | 14 | 3 | | | | 1 | 29 | 3 | | | | | | |
| Mexico | 2 | 30 | 23 | 7 | 7 | 2 | 30 | 7 | | | | | | | | | |
| Netherlands | 3 | 465 | 256 | 209 | 40 | | | | 3 | 465 | 40 | | | | | | |
| New Zealand | 1 | 22 | 13 | 9 | 2 | | | | 1 | 22 | 2 | | | | | | |
| Norway | 7 | 283 | 155 | 128 | 34 | | | | 6 | 224 | 23 | 1 | 59 | 11 | | | |
| Portugal | 1 | 8 | 7 | 1 | 1 | | | | | | | | | | 1 | 8 | 1 |
| Russia (including Courland and Finland) | 10 | 584 | 363 | 221 | 59 | 3 | 122 | 10 | 5 | 217 | 26 | 2 | 245 | 23 | | | |
| Spain | 7 | 222 | 125 | 97 | 16 | | | | | | | 7 | 222 | 16 | | | |
| Sweden | 17 | 680 | 421 | 259 | 76 | 2 | 111 | 9 | 3 | 68 | 10 | 5 | 324 | 35 | 7 | 177 | 22 |
| Switzerland | 11 | 380 | 182 | 198 | 39 | | | | 11 | 380 | 39 | | | | | | |
| United States | 55 | 7,155 | 4,085 | 3,070 | 481 | 8 | 346 | 26 | 12 | 584 | 62 | 35 | 6,225 | 393 | | | |
| Total | 397 | 26,473 | 10,751 | 8,545 | 2,029 | 32 | 1,642 | 130 | 239 | 13,246 | 1,182 | 91 | 10,566 | 654 | 37 | 1,019 | 63 |

* The reports from France and Prussia do not indicate the sex of the pupils.

TABLE W.—*A partial list of deaf children of deaf parents.*

| Name. | Where educated. | When admitted. | Age. | Remarks. |
|---|---|---|---|---|
| Acheson, Charles | American Asylum | 1864 | 10 | Both parents deaf-mutes. |
| Acheson, Dutee W | New England Industrial School | 1881 | 8 | Do. |
| Acheson, Eugene A | American Asylum | 1870 | 8 | Do. |
| Acheson, George W | ......do | 1864 | 11 | Do. |
| Acheson, Pauline M | Horace Mann School | 1872 | 5 | Do. |
| Do | American Asylum | 1878 | 11 | Do. |
| Acheson, Robert | ......do | 1869 | 10 | Do. |
| Allard, Hattie M | ......do | 1871 | 8 | Do. |
| Allen, Asa W | ......do | 1845 | 9 | Do. |
| Allen, Eliza | ......do | 1849 | 9 | Do. |
| Allen, Mabel H | ......do | 1881 | 8 | Father a deaf-mute. |
| Allen, Sarah | ......do | 1843 | 10 | Both parents deaf-mutes. |
| Arnold, Fanny | New York Institution | 1835 | 10 | Mother a deaf-mute. |
| Arnold, Jane | ......do | 1833 | 15 | Do. |
| Atherholt, Colonel | Ohio Institution | 1851 | 13 | Mother a deaf-mute. |
| Ballin, Albert | New York Institution | 1868 | 7 | Father a deaf mute. |
| Barnard, Lucretia R | American Asylum | 1863 | 10 | Both parents deaf mutes. |
| Barnes, Rosa I | Western New York Institution | 1883 | 6 | Do. |
| Bayne, Mary E | Pennsylvania Institution | 1878 | 10 | Do. |
| Belcke, Charles | Illinois Institution | 1879 | 9 | Do. |
| Berry, Francis | New England Industrial School | 1883 | 12 | Do. |
| Bender, Caroline | New York Institution | 1859 | 14 | Father partially deaf. |
| Bennett Mary L | Pennsylvania Institution | 1875 | 9 | Both parents deaf mutes. |
| Do | New York Institution | 1882 | 16 | Do. |
| Bentz, Anna De H | Pennsylvania Institution | 1869 | 11 | Do. |
| Bodine, Charles Van W | New York Institution | 1867 | 7 | Both parents "hard of hearing." |
| Brasher, Fanny C | Illinois Institutioa | 1882 | 13 | Do. |
| Brown, Susan F | American Asylum | 1865 | 14 | Father a deaf-mute. |
| Brown, Thomas | ......do | 1822 | 18 | Do. |
| Brown, Thomas L | ......do | 1851 | 12 | Both parents deaf-mutes. |
| Brown, Helen H | ......do | 1855 | 13 | Mother a deaf-mute. |
| Bruner, Harry A | Western New York Institution | 1876 | 10 | Mother somewhat deaf. |
| Bucklen, Simeon D | New York Institution | 1842 | 12 | Father a deaf-mute. |
| Bucklen, Martha Ann | ......do | 1838 | 12 | Do. |
| Burgess, W. Taylor | West Virginia Institution | 1878 | 21 | Both parents deaf-mutes. |
| Burgess, Jane E | ......do | 1880 | 19 | Do. |
| Burt, Harrison A | New York Institution | 1863 | 15 | Mother partially deaf. |
| Butler, Phœbe M | ......do | 1878 | 18 | Father deaf in one ear. |
| Cairnes, William T | Maryland School | 1881 | 10 | Both parents deaf-mutes. |
| Campbell, Lizzie | Clarke Institution | 1877 | 16 | Mother partially deaf. |
| Churchill, Anna R | New York Institution | 1858 | 12 | Father "hard of hearing." |
| Cook, Elizabeth | ......do | 1851 | 13 | Both parents deaf-mutes. |
| Cooper, William E | Minnesota School | 1863 | 11 | Both parents slightly deaf. |
| Crawford, Josephine L | ......do | 1879 | 21 | Mother somewhat deaf. |
| Culver, Annie J | American Asylum | 1878 | 9 | Both parents deaf-mutes. |
| Culver, John | ......do | 1883 | 11 | Do. |
| Culver, Heman M | ......do | 1881 | 9 | Do. |
| Daniels, Willie E | New England Industrial School | 1882 | 7 | Do. |
| Derby, Ira H | American Asylum | 1861 | 11 | Do. |
| Diamond, Albert | Le Couteaux St. Mary's Institution | 1867 | 9 | Do. |
| Dithorn, Mary E | Pennsylvania Institution | 1859 | 10 | Do. |
| Driskell, Elsie A | Illinois Institution | 1867 | 8 | Do. |
| Duntz, Caroline | New York Institution | 1855 | (?) | Father deaf in one ear. |
| Dupee, Franklin L | Oral Branch Penn Institution | 1882 | 10 | Mother slightly deaf. |
| Edwards, Walter D | Illinois Institution | 1864 | 8 | Both parents deaf-mutes. |
| Edwards, Mary E | ......do | 1867 | 10 | Do. |
| Felton, John | Wisconsin Institution | 1869 | 14 | Mother a deaf-mute. |
| Genet, William F | New York Institution | 1859 | 13 | Both parents deaf-mutes. |
| George, Dudley W | Columbia Institution | 1871 | 16 | Do. |
| Getman, Ida | New York Institution | 1874 | 7 | Do. |

TABLE W.—*A partial list of deaf children of deaf parents*—Continued.

| Name. | Where educated. | When admitted. | Age. | Remarks. |
|---|---|---|---|---|
| Gloyne, Mary | New York Institution | 1868 | 7 | Mother "hard of hearing." |
| Goodness, Alex | Wisconsin Institution | 1874 | 17 | Father a deaf-mute. |
| Hahn, Maximilian | New York Institution | 1868 | 13 | Father partially deaf |
| Hall, William Franklin | do | 1865 | 12 | Both parents deaf-mutes. |
| Hall, Florilla | Western New York Institution | 1883 | 6 | Mother a deaf-mute. |
| Hemricks, Henry | Minnesota School | 1870 | 20 | Father very deaf. |
| Hine, James | American Asylum | 1846 | 8 | Both parents deaf-mutes. |
| Hines, William W | Ohio Institution | 1878 | 9 | Do. |
| Hord, Edwin | Missouri Institution | 1864 | 14 | Father a deaf-mute. |
| Hord, Mary E | do | 1866 | 11 | Do. |
| Howell, Wallace F | New York Institution | 1865 | 10 | Do. |
| Howell, William L | do | 1868 | 9 | Do. |
| Housel, Helen Estelle | do | 1875 | 7 | Both parents deaf-mutes. |
| Jones, Florence Harriet | do | 1864 | 7 | Do. |
| Kershner, John M | Pennsylvania Institution | 1880 | 11 | Do. |
| Kershner, Emma R | do | 1883 | 10 | Do. |
| Kindred, Maria J | Illinois Institution | 1860 | 15 | Father a deaf-mute. |
| Kindred, Elizabeth | do | 1860 | 13 | Do. |
| Kingsley, Isabella | American Asylum | 1833 | 13 | Mother a deaf-mute. |
| Koffman, Abey | New York Institution | 1868 | 15 | Father "hard of hearing." |
| Koffman, Samuel | do | 1868 | 12 | Do. |
| Koffman, Lewis | do | 1868 | 10 | Do. |
| Laird, James F | Pennsylvania Institution | 1862 | 14 | Both parents deaf-mutes. |
| Laird, Elizabeth I | do | 1867 | 11 | Do. |
| Laister, Eleanor Jane | New York Institution | 1849 | 12 | Father a deaf-mute. |
| Lancaster, Lucas C | do | 1877 | 14 | Mother deaf in one ear. |
| Lloyd, John, jr | do | 1878 | 17 | "Father deaf from old age." |
| Lovejoy, Benjamin | American Asylum | 1844 | 15 | Father a deaf-mute. |
| Lovejoy, Hartwell | do | 1851 | 17 | Do. |
| Lovejoy, Sarah | do | 1851 | 15 | Do. |
| Lovejoy, Emma | do | 1851 | 10 | Do. |
| Lovejoy, Erastus | do | 1860 | 17 | Do. |
| Lovejoy, Abigail | do | 1860 | 12 | Do. |
| Lovejoy, Lydia A | do | 1867 | 10 | Do. |
| Lovejoy, Hattie M | do | 1873 | 9 | Do. |
| Lovejoy, Roscoe P | New England Industrial School | 1883 | 15 | Do. |
| Marsh, Catharine B | American Asylum | 1852 | 10 | Both parents deaf-mutes. |
| Marsh, Paulina N | do | 1855 | 10 | Do. |
| Marsh, Jonathan F | do | 1860 | 11 | Do. |
| Marshall, George W | Illinois Institution | 1863 | 10 | Do. |
| Marshall, Benjamin F | do | 1866 | 9 | Do. |
| Marshall, Edith H | American Asylum | 1879 | 11 | Do. |
| Marshall, Gilbert F | do | 1879 | 9 | Do. |
| Marshall, Leslie G | do | 1882 | 8 | Do. |
| Mayhew, Benjamin | do | 1858 | 12 | Do. |
| Mayhew, Jared | do | 1864 | 11 | Do. |
| Mayo, Hawes | do | 1865 | 10 | Mother a deaf-mute. |
| McClave, Robert | Ohio Institution | 1865 | 12 | Both parents deaf-mutes. |
| McClurg, Drucilla H | Pennsylvania Institution | 1877 | 12 | Do. |
| McGregor, Bessie | Ohio Institution | 1883 | 5 | Do. |
| McLaughlin, Amanda | Western New York Institution | 1876 | 6 | Do. |
| Meacham, Mary O | American Asylum | 1866 | 14 | Mother a deaf-mute. |
| Meacham, Marcellia A | do | 1866 | 9 | Do. |
| Meacham, George | do | 1868 | - | Do. |
| Meacham, Allen B | do | 1872 | 11 | Both parents deaf-mutes. |
| Meade, Margaret | Minnesota School | 1873 | 10 | Mother very hard of hearing. |
| Metrash, Robert L. G | American Asylum | 1872 | 8 | Both parents deaf-mutes. |
| Munson, Lizzie | New York Institution | 1879 | 9 | Mother partially deaf (recent). |
| Ormsby, Edward E | New York Institution | 1870 | 13 | Mother "hard of hearing." |
| Park, James M | Columbia Institution | 1871 | 19 | Both parents deaf-mutes. |
| Do | Ohio Institution | 1864 | 12 | Do. |

TABLE W.—*A partial list of deaf children of deaf parents*—Continued.

| Name. | Where educated. | When admitted. | Age. | Remarks. |
|---|---|---|---|---|
| Pier, John W | Ohio Institution | 1876 | 8 | Both parents deaf-mutes. |
| Place, Larissa | New York Institution | 1863 | 14 | Father a deaf-mute. |
| Pimm, Joshua R | do | 1858 | 9 | Both parents deaf-mutes. |
| Pimm, Rachel A | do | 1861 | 11 | Do. |
| Pimm, Martha | do | 1864 | 13 | Do. |
| Pimm, Charles Augustus | do | 1867 | [illegible] | Do. |
| Purvis, James H | Columbia Institution | 1865 | 16 | Do. |
| Purvis, Amanda J | Pennsylvania Institution | 1865 | 12 | Do. |
| Purvis, Kate L | do | 1870 | 12 | Do. |
| Purvis, Mary | do | 1872 | 15 | Do. |
| Purvis, Mary A | do | 1871 | 11 | Do. |
| Purvis, Timothy | do | 1872 | 9 | Do. |
| Purvis, James M | do | 1880 | 11 | Do. |
| Riggs, Charles A | American Asylum | 1878 | 10 | Do. |
| Ramsey, Ann E | Pennsylvania Institution | 1849 | 12 | Mother a deaf-mute. |
| Redmond, Henry | New York Institution | 1883 | 7 | Both parents deaf-mutes. |
| Richardson, George E | Clarke Institution | 1880 | 6 | Mother partially deaf. |
| Risley, Luman L | New York Institution | 1856 | 13 | Both parents deaf-mutes. |
| Risley, Charles E | do | 1870 | 6 | Do. |
| Roberts, John James | do | 1877 | 8 | Father deaf in one ear. |
| Rogers, Jane I | South Carolina Institution | 1855 | 9 | Both parents deaf-mutes. |
| Rogers, William H | do | 1858 | 10 | Do. |
| Rogers, David S | do | 1860 | 11 | Do. |
| Do | Columbia Institution | 1868 | 17 | Do. |
| Rogers, Laura A | South Carolina Institution | 1867 | 10 | Do. |
| Rogers, Clara A | do | 1869 | 10 | Do. |
| Rogers, Nettie S., daughter of Wm. H. Rogers | do | 1880 | 7 | Do. |
| Sawhill, Collins S | Columbia Institution | 1878 | 21 | Do. |
| Do | Ohio Institution | 1871 | 14 | Do. |
| Do | Pennsylvania Institution | 1869 | 12 | Do. |
| Sawhill, Isaac H | Ohio Institution | 1870 | 12 | Do. |
| Do | Columbia Institution | 1878 | 20 | Do. |
| Sawhill, Jesse U | Ohio Institution | 1871 | 9 | Do. |
| Sawhill, William L | do | 1873 | 10 | Do. |
| Sawhill, Lavinia A | do | 1876 | 8 | Do. |
| Schroeder, Anthony | Minnesota School | 1877 | 10 | Father very deaf. |
| Scovel, Harriet E | American Asylum | 1818 | 14 | Father a deaf-mute. |
| Scovel, Steven | do | 1838 | 25 | Do. |
| Scovel, Olive | do | 1858 | 15 | Do. |
| Shannon, William | New York Institution | 1870 | 12 | Mother "hard of hearing." |
| Skelsy, John | do | 1855 | 15 | Mother becoming deaf. |
| Stevenson, Charles W | Columbia Institution | 1863 | 12 | Both parents deaf-mutes. |
| Do | Maryland School | 1868 | 14 | Do. |
| Stevenson, Georgiana | Columbia Institution | 1863 | 9 | Do. |
| Stiles, Penniah Anna | New York Institution | 1868 | 11 | Father a little deaf. |
| Stratton, Sarah C | Pennsylvania Institution | 1857 | 12 | Mother a deaf-mute. |
| Stratton, James Wells | New York Institution | 1874 | 7 | Both parents deaf-mutes. |
| Straw, Mary | Ohio Institution | 1869 | 12 | Father a deaf-mute. |
| Suart, Emma M | Illinois Institution | 1883 | 12 | Mother partially deaf. |
| Suart, Mabel C | do | 1883 | 11 | Do. |
| Sutton, Ross P | Ohio Institution | 1883 | 10 | Both parents deaf-mutes. |
| Swett, Persis B | American Asylum | 1863 | 11 | Do. |
| Swett, Charlotte E | do | 1872 | 11 | Do. |
| Swett, Mitchel | do | 1873 | 11 | Do. |
| Swett, Lucy Maria | Clarke Institution | 1882 | 18 | Do. |
| Sweet, Margaret S | American Asylum | 1875 | 9 | Do. |
| Tate, Margaret | Missouri Institution | 1870 | (?) | Mother a deaf-mute. |
| Taylor, Anna R | American Asylum | 1851 | 13 | Do. |
| Townsend, Albert M | Illinois Institution | 1873 | 12 | Both parents deaf-mutes. |
| Turner, Lucy M | American Asylum | 1864 | 15 | Do. |
| Van Kirk, Joseph S | Pennsylvania Institution | 1856 | 11 | Do. |

TABLE W.—*A partial list of deaf children of deaf parents*—Continued.

| Name. | Where educated. | When admitted. | Age. | Remarks. |
|---|---|---|---|---|
| Van Kirk, John | Pennsylvania Institution | 1859 | 11 | Both parents deaf mutes. |
| Van Kirk, Charles H | do | 1861 | 11 | Do. |
| Vaughn, Emily W | Illinois Institution | 1877 | 9 | Do. |
| Watson, Frederick W | California Institution | 1883 | 15 | Mother a deaf mute. |
| Webster, Joseph | New York Institution | 1850 | 12 | Father a deaf-mute. |
| Wells, Anna E | Illinois Institution | 1863 | 19 | Mother deaf adult life. |
| Wells, Helen D | Maryland School | 1883 | 8 | Both parents deaf mutes. |
| West, Rebecca T | American Asylum | 1856 | 12 | Mother a deaf-mute. |
| West, George | do | 1861 | 13 | Do. |
| West, Benjamin D | do | 1868 | 15 | Both parents deaf mutes. |
| West, Deidama J | do | 1868 | 12 | Do. |
| Wildfaog, Daniel | Wisconsin Institution | 1860 | 12 | Mother a deaf mute. |
| Wildfang, Addie | do | 1883 | 8 | Both parents deaf-mutes. |
| Williams, Laura | New York Institution | 1833 | 12 | Father a deaf-mute. |
| Williams, Elizabeth | do | 1846 | 12 | Both parents deaf and dumb. |
| Williams, Harriet | do | 1850 | 12 | Do. |
| Weidt, William | Louisiana Institution | 1883 | 13 | Do. |
| Weidt, A | do | 1883 | 11 | Do. |
| Weidt, Annie | do | 1883 | 8 | Do. |
| Wise, George A | New England Industrial School | 1881 | 11 | Do. |
| Wise, Lottie | do | 1881 | 8 | Do. |
| Wolpert, David H | Colorado Institution | 1874 | 7 | Father deaf in one ear. |
| Woolever, Margaret Ann | New York Institution | 1863 | 12 | Mother partially deaf. |
| Worcester, Ira E | American Asylum | 1879 | 9 | Both parents deaf-mutes. |
| Works, William S | New York Institution | 1848 | 15 | Do. |
| Works, Martha Jane | do | 1848 | 13 | Do. |
| Works, Mary Ann | do | 1851 | 13 | Do. |
| Works, Charles H | do | 1855 | (?) | Do. |
| Whittington, Louis | Columbia Institution | 1869 | (?) | Mother a deaf-mute. |
| Wyncoop, Cora A | New York Institution | 1856 | (?) | Father a deaf-mute. |
| Wyncoop, Frederick | Western New York Institution | 1877 | 11 | Mother a deaf-mute. |
| Zimmerman, Alice | Maryland School | 1879 | 8 | Both parents deaf-mutes. |
| Zimmerman, Jennie | do | 1883 | 9 | Do. |

TABLE X.—*Showing per capita cost for the education of a deaf child in an American institution.*

| Name of institution. | Number of pupils Dec. 1, 1881. | Amount expended for support. | Per capita. |
|---|---|---|---|
| American Asylum, Hartford Conn | 180 | $47,641 | $264 67 |
| New York Institution, New York City | 481 | 131,307 | 273 00 |
| Pennsylvania Institution | 319 | 71,301 | 223 51 |
| Kentucky Institution | 139 | 26,705 | 192 12 |
| Ohio Institution | 432 | 79,612 | 184 28 |
| Virginia Institution | 85 | 19,185 | 225 70 |
| Indiana Institution | 325 | 54,831 | 165 48 |
| Tennessee Institution | 103 | 24,369 | 236 59 |
| North Carolina Institution | 99 | 34,000 | 344 44 |
| Illinois Institution | 508 | 85,000 | 167 32 |
| Georgia Institution | 47 | 14,241 | 230 00 |
| South Carolina Institution | 37 | 8,092 | 218 70 |
| Iowa Institution | 192 | 37,359 | 194 57 |
| Wisconsin Institution | 478 | 40,888 | 229 14 |
| Michigan Institution | 249 | 43,603 | 175 11 |
| Mississippi Institution | 67 | 10,610 | 149 25 |
| Columbia Institution (including the National College) | 117 | 51,108 | 496 64 |
| Alabama Institution | 44 | 12,500 | 284 09 |
| California Institution † | 108 | 35,352 | 327 30 |
| Missouri Institution | 190 | 43,416 | 226 40 |
| Kansas Institution ‡ | 146 | 19,500 | 133 56 |
| Le Conteaux St. Mary's | 128 | 19,100 | 148 43 |
| Minnesota Institution | 112 | 24,425 | 218 03 |
| Improved Instruction Institution, New York | 137 | 35,454 | 258 78 |
| Clarke Institution, Massachusetts | 88 | 25,437 | 287 00 |
| Arkansas Institution | 59 | 13,600 | 230 55 |
| Maryland Institution | 84 | 23,189 | 276 02 |
| St. Joseph's Institution * | 250 | 27,588 | 110 35 |
| West Virginia Institution | 78 | 19,472 | 249 64 |
| Oregon Institution | 26 | 4,000 | 153 84 |
| Colorado Institution | 39 | 7,579 | 194 33 |
| Central New York Institution | 160 | 34,287 | 214 29 |
| Western Pennsylvania Institution | 104 | 19,011 | 182 79 |
| Western New York Institution | 116 | 27,901 | 240 52 |
| Total | 5,247 | 1,171,571 | 223 28 |

* Conducted by sisters of charity; no salaries paid.
† Has a blind department.
‡ Superintendent's last report states *per capita* cost $183.05.

TABLE Y.—*Tabular statement concerning the teaching of articulation in the institutions of the United States, May, 1883.*

| No | Name. | Location. | Date of opening. | Chief executive officer. | Articulation teacher first employed. | Employed constantly since? | No. teachers of articulation now employed. | No. pupils in institution. | No. receiving instruction in articulation. | No. using it as a means of instruction. | No. taught articulation, but not using it as a means of instruction. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | American Asylum | Hartford, Conn | 1817 | Job Williams, M. A., principal | 1855 | No.(a) | 2 | 188 | 35 | None | 35 |
| 2 | New York Institution | Washington Heights, New York, N. Y. | 1818 | Isaac Lewis Peet, LL. D., principal; Carlton Carson M. D., superintendent and resident physician | 1818 | No.(b) | 8 | 448 | 200 | 33 | 167 |
| 3 | Pennsylvania Institution | Philadelphia, Pa | 1820 | Joshua Foster, principal | 1870 | Yes. | 2 | 315 | 70 | None | 70 |
| 4 | Kentucky Institution | Danville, Ky | 1823 | D. C. Dudley, M. A., superintendent | | | None. | 146 | 6 | (c)6 | None |
| 5 | Ohio Institution | Columbus, Ohio | 1829 | Benjamin Talbot, M. A., acting superintendent | 1868 | Yes. | 2 | 430 | 80 | None. | 80 |
| 6 | Virginia Institution | Staunton, Va | 1839 | Charles S. Roller, principal | 1876 | Yes. | 1 | 57 | 16 | 10 | 6 |
| 7 | Indiana Institution | Indianapolis, Ind | 1844 | William Glenn, superintendent | 1876 | Yes. | 1 | 327 | 41 | None | 41 |
| 8 | Tennessee School | Knoxville, Tenn | 1845 | Thomas L. Moses, principal | 1880 | Yes. | 1 | 102 | 13 | 13 | None. |
| 9 | North Carolina Institution | Raleigh, N. C | 1844 | W. J. Young, principal | 1880 | Yes. | 1 | 80 | 10 | 10 | None. |
| 10 | Illinois Institution | Jacksonville, Ill | 1846 | Philip G. Gillett, LL. D., superintendent | 1868 | Yes. | 3 | 523 | 133 | None | 133 |
| 11 | Georgia Institution | Cave Spring, Ga | 1846 | W. O. Connor, principal | | | None. | 76 | 8 | None | 8 |
| 12 | South Carolina Institution | Cedar Spring, S. C | 1849 | Newton F. Walker, superintendent | 1880 | Yes | 1 | 48 | 6 | 6 | None. |
| 13 | Missouri Institution | Fulton, Mo | 1851 | William D. Kerr, M. A., superintendent | 1874 | Yes. | 2 | 192 | 55 | None | 55 |
| 14 | Louisiana Institution | Baton Rouge, La | 1852 | R. G. Ferguson, M. A., superintendent | | | None. | 32 | (d)4 | None. | 4 |
| 15 | Wisconsin Institution | Delavan, Wis | 1852 | John W. Swiler, M. A., superintendent | 1868 | Yes. | 1 | 190 | 33 | 33 | None |
| 16 | Michigan Institution | Flint, Mich | 1854 | F. A. Platt, M. A., principal; Dan H. Church, superintendent. | 1876 | Yes | 1 | 245 | 28 | (e)28 | None |
| 17 | Iowa Institution | Council Bluffs, Iowa | 1855 | Rev. A. Rogers, superintendent | 1878 | No (f) | 1 | 270 | 28 | 10 | 18 |
| 18 | Mississippi Institution | Jackson, Miss | 1856 | J. R. Dobyns, superintendent | 1882 | Yes. | 1 | 72 | 24 | None. | 24 |
| 19 | Texas Asylum | Austin, Texas | 1857 | John S. Ford, superintendent | (g)1879 | No (h) | None | 87 | None. | None. | None |
| 20 | Columbia Institution | Washington, D. C | 1857 | E. M. Gallaudet, Ph. D., LL. D., president | 1870 | Yes. | 1 | 51 | 34 | None | 34 |
| 21 | Alabama Institution | Talladega, Ala | 1860 | Joseph H. Johnson, M. D., principal | | | None. | 45 | None. | None | None |
| 22 | California Institution | Berkeley, Cal | 1860 | Warren Wilkinson, M. A., principal | 1881 | Yes | 1 | 116 | 45 | None | 45 |
| 23 | Kansas Institution | Olathe, Kans | 1862 | G. L. Wyckoff, acting superintendent | 1882 | Yes. | 1 | 157 | 32 | 12 | 20 |
| 24 | Le Couteulx St. Mary's Institution | Buffalo, N. Y | 1862 | Sister Mary Anne Burke, principal | 1873 | Yes. | 1 | 153 | 91 | 17 | 74 |
| 25 | Minnesota Institution | Faribault, Minn | 1863 | Jonathan L. Noyes, M. A., superintendent | 1880 | Yes. | 1 | 127 | 32 | 6 | 26 |
| 26 | Institution for Improved Instruction | New York, N. Y | 1867 | D. Greenberger, principal | 1867 | Yes | 11 | 166 | 166 | 166 | None |
| 27 | Clarke Institution | Northampton, Mass | 1867 | Miss Harriet B. Rogers, principal | 1867 | Yes | 12 | 85 | 86 | 85 | None. |
| 28 | Arkansas Institute | Little Rock, Ark | 1868 | H. C. Hammond, M. A., principal | | | None. | 52 | None. | None | None |
| 29 | Maryland School | Frederick City, Md | 1868 | Charles W. Ely, M. A., principal | 1871 | Yes | 2 | 89 | 66 | None. | (i)66 |
| 30 | Nebraska Institute | Omaha, Nebr | 1869 | J. A. Gillespie, B. D., principal | 1884 | Yes | 2 | 94 | 56 | 13 | 43 |
| 31 | Horace Mann School | Boston, Mass | 1869 | Miss Sarah Fuller, principal | 1869 | Yes. | 8 | 83 | 83 | 83 | None |
| 32 | Whipple's Home School | Mystic River, Conn | 1869 | J. Whipple, proprietor | 1868 | Yes. | 2 | 12 | 12 | 12 | None |

(a) "Interval of 5 years, 1863–1868. (b) "Employed, 1818–1821; 1846 one year, and from 1867 to present time." (c) "Semi mutes taught almost wholly by lip reading." (d) "Taught by principal." (e) "To some extent." (f) "Fire interrupted." (g) "Also in 1880 and 1882." (h) "Could not procure teacher." (i) "We now give all our young pupils at least a year's careful instruction in speech before deciding whether the effort shall be discontinued or not."

TABLE Y.—*Tabular statement concerning the teaching of articulation in the institutions of the United States, May, 1883*—Continued.

| No. | Name. | Location. | Date of opening. | Chief executive officer. | Articulation teacher first employed. | Employed constantly since? | No. teachers of articulation now employed. | No. pupils in institution. | No. receiving instruction in articulation. | No. using it as a means of instruction. | No. taught articulation, but not using it as a means of instruction. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 33 | St. Joseph's Institute | Fordham, N. Y | 1869 | Miss Mary B. Morgan, superintendent | 1870 | Yes. | 6 | 241 | (a)89 | 75 | 14 |
| 34 | West Virginia Institution | Romney, W. Va | 1870 | J. C. Covell, M. A., principal | 1877 | No.(b) | None. | 66 | None | None. | None. |
| 35 | Oregon School | Salem, Oreg | 1870 | Rev. P. S. Knight, principal | | | None. | 23 | None. | None. | None. |
| 36 | Institution for Colored | Baltimore, Md | 1872 | F. D. Morrison, M. A., superintendent | | | None. | 13 | None. | None. | None. |
| 37 | Ev. Lutheran Institution | Norris, Mich | 1873 | H. D. Uhlig, principal | 1873 | Yes. | 3 | 40 | 40 | 40 | None. |
| 38 | Colorado Institute | Colorado Springs, Colo | 1874 | P. W. Downing, principal; J. R. Kennedy, superintendent. | | | None. | 37 | (e)7 | 2 | 5 |
| 39 | Erie Day School | Erie, Pa | 1874 | Miss Mary Welsh, teacher | 1874 | Yes. | 1 | 10 | 10 | 10 | None. |
| 40 | Chicago Day Schools | Chicago, Ill | 1875 | P. A. Emery, M. A., principal | 1882 | Yes. | 1 | (d) | | | |
| 41 | Central New York Institution | Rome, N. Y | 1875 | Edward B. Nelson, B. A., principal | 1877 | Yes. | 1 | 163 | 25 | 20 | 5 |
| 42 | Cincinnati Day School | Cincinnati, Ohio | 1875 | A. F. Wood, principal | | | None. | 26 | None. | None. | None. |
| 43 | Western Pennsylvania Institution | Turtle Creek, Pa | 1876 | Thomas MacIntire, Ph. D., principal | 1882 | Yes. | 1 | 102 | 13 | 6 | 7 |
| 44 | Western New York Institution | Rochester, N. Y | 1876 | Z. F. Westervelt, principal | 1876 | Yes. | 4 | 136 | 125 | 5 | (e) 120 |
| 45 | Portland Day School | Portland, Me | 1876 | Miss Ellen L. Barton, principal | 1877 | Yes. | 4 | 33 | 33 | 33 | None. |
| 46 | St. John's Catholic Institute | Saint Francis, Wis | 1876 | Rev. Charles Fessler, principal | 1876 | Yes. | 2 | 42 | 34 | None. | 34 |
| 47 | Rhode Island School | Providence, R. I | 1877 | Miss Katharine H. Austin, principal | 1877 | Yes. | 3 | 30 | 30 | 30 | None. |
| 48 | Mr. Knapp's School | Baltimore, Md | 1877 | Frederick Knapp, principal | 1877 | Yes. | 4 | 40 | 40 | 40 | None. |
| 49 | Phonological Institute | Milwaukee, Wis | 1878 | Adam Stettner, principal | 1878 | Yes. | 2 | 21 | 21 | 21 | None. |
| 50 | Saint Louis Day School | Saint Louis, Mo | 1878 | D. A. Simpson, B. A., principal | | | None. | 41 | None. | None. | None. |
| 51 | New England Industrial School | Beverly, Mass | 1878 | William B. Swett, superintendent | 1880 | Yes. | 1 | 19 | 6 | 1 | 5 |
| 52 | School of Articulation | Marquette, Mich | 1877 | Mrs. A. M. Kelsey, principal | 1870 | Yes. | (f) | | | | |
| 53 | Scranton Day School | Scranton, Pa | 1880 | Jacob M. Koehler, principal | | | None. | 12 | None. | None. | None. |
| 54 | Dakota School | Sioux Falls, Dak | 1880 | James Simpson, superintendent | | | None. | 19 | None. | None. | (g) 2 |
| 55 | Oral Branch Pennsylvania Institution | Philadelphia, Pa | 1881 | Miss Emma Garrett, teacher in charge | 1881 | Yes. | 7 | 60 | 60 | 60 | None. |
| 55 | Institutions in the United States | | | | | | 112 | 6,232 | 1,991 | 886 | 1,105 |
| | National College | Washington, D. C | 1864 | E. M. Gallaudet, Ph. D., LL.D., president | 1877 | No.(h) | None. | 31 | None. | None. | None. |

(*a*) These figures seem not to do justice to the articulation work done. (*b*) "Only two years." (*c*) "Taught by principal and a hearing teacher." (*d*) "No further definite information." (*e*) "All will have practical use made of articulation as a means of instruction." (*f*) "School closed June, 1882." (*g*) "Semi-mutes, who converse orally with all who can hear." (*h*) Employed or 3 or 4 years; "discontinued because of interference with legitimate work of the college. With a few lip-readers, considerable use is made of speech in recitation."

# APPENDIX Z.

The following table, combining all the cases of marriage recorded in Tables A to J, was submitted to Prof. Simon Newcomb for his opinion regarding the number of congenital deaf-mutes who had married congenital deaf-mutes. The Reports of the American Asylum and Illinois Institution give no information bearing on this point; but it seemed possible to determine the probabilities from the data given in the table, especially as the intermarriages, in a large proportion of cases, undoubtedly occurred between deaf-mutes who had been educated in the same Institution, and who were therefore *both* included in the table:

| Cause of deafness. | Deaf-mutes who are recorded to have married deaf-mutes. | | | Deaf-mutes stated to have married, but who are not recorded to have married deaf-mutes. | | |
|---|---|---|---|---|---|---|
| | Males. | Females. | Total. | Males. | Females. | Total. |
| Congenital | 150 | 148 | 298 | 37 | 25 | 62 |
| Non-congenital | 179 | 152 | 331 | 58 | 27 | 85 |
| Not stated | 14 | 11 | 25 | 7 | 8 | 15 |
| Total | 343 | 311 | 654 | 102 | 60 | 162 |

The main question proposed was this: Of the congenital deaf-mutes who are recorded to have married deaf-mutes, what proportion have married *congenital* deaf-mutes?

Professor Newcomb has been kind enough to send the following letters in reply to the query:

NAUTICAL ALMANAC OFFICE, NAVY DEPARTMENT,
*Washington, D. C., May* 20, 1884.

DEAR MR. BELL: Although the question you ask seems to admit of a satisfactory answer, I notice a singular defect in the statistical table. It contains not a single case of a deaf-mute being reported as having married a hearing person. If this is an accidental omission in making the copy for you it ought to be corrected. If there is really no such record the case is very singular.* It would look as if the parties were ashamed to state that they had married hearing persons, or the recorders had rejected all such cases.

The main question you ask can, I think, be answered by the theory of probabilities. Your table, if I understand it correctly, shows that out of 629 persons in the institution (of whom 329 were males and 300 females) a little less than one-half (298) were congenital deaf-mutes. Now, I see no reason for supposing that the persons whom they married would be divided in any essentially different proportion between the two classes.

It is true that could we learn from the census tables how the entire deaf of the country of marriageable ages, say, between the ages of twenty and thirty, are divided between the two classes, our conclusions might be modified. If, for example, it should be found that of the total number of deaf alluded to only one-third were congenital cases, we

* Only eleven deaf-mutes were specifically stated to have married hearing persons, and 151 were recorded simply as "married."

might be allowed to suppose that the marriages reported were divided according to this ratio, rather than according to the approximate ratio of equality found in the asylum. But we should consider that this surplus of non-congenital deaf would indicate a class who associate principally with hearing persons, and who would, therefore, be less likely to marry deaf-mutes than others would. I think, therefore, that under the circumstances, we should regard the ratio given by statistics of the institution as the most probable one. Of course the reason for this is strengthened if, as you intimate, a large proportion of the statistics may be mutual. Allowing for a probable slight tendency of the two classes congenital and non-congenital to choose each other, I think the most probable conclusion would be this:

Of the congenital deaf *one-half* married congenital and *one-half* non-congenital deaf.

Of the non-congenital *three-sevenths* married congenital deaf and *four-sevenths* non-congenital deaf.

And I consider these results sufficiently probable to form the basis of conclusions in cases where slight changes in the numbers would not change the general result.

If you wish your table returned please inform me.

Yours, very truly,

S. NEWCOMB.

WASHINGTON, D. C., *May* 26, 1884.

DEAR MR. BELL: The remarkable agreement between the ratio of congenital and non-congenital cases in the census reports, and in the numbers married, affords a strong confirmation of the probable soundness of the conclusion I indicated to you. The small discrepancy to which you allude probably arose from the twenty-five "not stated" cases. I return you the tables.

Yours, very truly,

S. NEWCOMB.