34th Congress, } HOUSE OF REPRESENTATIVES. { Mis Doc.
1st Session. } { No. 113.

TENTH ANNUAL REPORT

OF THE

BOARD OF REGENTS

OF THE

SMITHSONIAN INSTITUTION,

SHOWING THE

OPERATIONS, EXPENDITURES, AND CONDITION OF THE INSTITUTION, UP TO JANUARY 1, 1856.

AND THE

PROCEEDINGS OF THE BOARD UP TO MARCH 22, 1856.

WASHINGTON:
CORNELIUS WENDELL, PRINTER.
1856.

LETTER

OF THE

SECRETARY OF THE SMITHSONIAN INSTITUTION,

COMMUNICATING

The Tenth Annual Report of the Board of Regents of that Institution.

MAY 23, 1856.—Laid upon the table, and ordered to be printed.

AUGUST 9, 1856.—*Resolved,* That there be printed, for the use of the members of the present House of Representatives, 7,500 copies of the Report of the Regents of the Smithsonian Institution, and 2,500 copies of the same Report for the use of the Smithsonian Institution.

SMITHSONIAN INSTITUTION,
Washington, May 23, 1856.

SIR: In behalf of the Board of Regents, I have the honor to submit to the House of Representatives of the United States, the Tenth Annual Report of the operations, expenditures, and condition of the Smithsonian Institution.

I have the honor to be, very respectfully, your obedient servant,

JOSEPH HENRY,
Secretary Smithsonian Institution.

Hon. NATHANIEL P. BANKS, Jr.,
Speaker of the House of Representatives.

TENTH ANNUAL REPORT

OF THE

BOARD OF REGENTS

OF THE

SMITHSONIAN INSTITUTION,

SHOWING

THE OPERATIONS, EXPENDITURES, AND CONDITION OF THE INSTITUTION UP TO JANUARY 1, 1856, AND THE PROCEEDINGS OF THE BOARD UP TO MARCH 22, 1856.

To the Senate and House of Representatives:

In obedience to the act of Congress of August 10, 1846, establishing the Smithsonian Institution, the undersigned, in behalf of the Regents, submit to Congress, as a Report of the operations, expenditures, and condition of the Institution, the following documents:

1. The Annual Report of the Secretary, giving an account of the operations of the Institution during the year 1855.
2. Report of the Executive Committee, giving a general statement of the proceeds and disposition of the Smithsonian fund, and also an account of the expenditures for the year 1855.
3. Report of the Building Committee for 1855.
4. Proceedings of the Board of Regents up to March 22, 1856.
5. Appendix.

Respectfully submitted:

R. B. TANEY, *Chancellor.*
JOSEPH HENRY, *Secretary.*

OFFICERS OF THE SMITHSONIAN INSTITUTION.

FRANKLIN PIERCE, *Ex officio* Presiding Officer of the Institution.
ROGER B. TANEY, Chancellor of the Institution.
JOSEPH HENRY, Secretary of the Institution.
SPENCER F. BAIRD, Assistant Secretary.
W. W. SEATON, Treasurer.
WILLIAM J. RHEES, Chief Clerk.

ALEXANDER D. BACHE, JAMES A. PEARCE, JOSEPH G. TOTTEN,	Executive Committee.
RICHARD RUSH, WILLIAM H. ENGLISH, JOHN T. TOWERS, JOSEPH HENRY,	Building Committee.

REGENTS OF THE INSTITUTION.

——— ———, Vice President of the United States.
ROGER B. TANEY, Chief Justice of the United States.
JOHN T. TOWERS, Mayor of the City of Washington.
JAMES A. PEARCE, member of the Senate of the United States.
JAMES M. MASON, member of the Senate of the United States.
STEPHEN A. DOUGLAS, member of the Senate of the United States.
WILLIAM H. ENGLISH, member of the House of Representatives.
HIRAM WARNER, member of the House of Representatives.
BENJAMIN STANTON, member of the House of Representatives.
GIDEON HAWLEY, citizen of New York.
RICHARD RUSH, citizen of Pennsylvania.
GEORGE E. BADGER, citizen of North Carolina.
CORNELIUS C. FELTON, citizen of Massachusetts.
ALEXANDER D. BACHE, citizen of Washington.
JOSEPH G. TOTTEN, citizen of Washington.

MEMBERS EX OFFICIO OF THE INSTITUTION.

FRANKLIN PIERCE, President of the United States.
——— ———, Vice President of the United States.
WILLIAM L. MARCY, Secretary of State.
JAMES GUTHRIE, Secretary of the Treasury.
JEFFERSON DAVIS, Secretary of War.
JAMES C. DOBBIN, Secretary of the Navy.
JAMES CAMPBELL, Postmaster General.
CALEB CUSHING, Attorney General.
ROGER B. TANEY, Chief Justice of the United States.
CHARLES MASON, Commissioner of Patents.
JOHN T. TOWERS, Mayor of the City of Washington.

HONORARY MEMBERS.

ROBERT HARE, of Pennsylvania.
WASHINGTON IRVING, of New York.
BENJAMIN SILLIMAN, of Connecticut.
PARKER CLEAVELAND, of Maine.

PROGRAMME OF ORGANIZATION

OF THE

SMITHSONIAN INSTITUTION.

[PRESENTED IN THE FIRST ANNUAL REPORT OF THE SECRETARY, AND ADOPTED BY THE BOARD OF REGENTS, DECEMBER 13, 1847.]

INTRODUCTION.

General considerations which should serve as a guide in adopting a Plan of Organization.

1. Will of Smithson. The property is bequeathed to the United States of America, "to found at Washington, under the name of the Smithsonian Institution, an establishment for the increase and diffusion of knowledge among men."

2. The bequest is for the benefit of mankind. The Government of the United States is merely a trustee to carry out the design of the testator.

3. The Institution is not a national establishment, as is frequently supposed, but the establishment of an individual, and is to bear and perpetuate his name.

4. The objects of the Institution are, 1st, to increase, and 2d, to diffuse knowledge among men.

5. These two objects should not be confounded with one another. The first is to enlarge the existing stock of knowledge by the addition of new truths; and the second, to disseminate knowledge, thus increased, among men.

6. The will makes no restriction in favor of any particular kind of knowledge; hence all branches are entitled to a share of attention.

7. Knowledge can be increased by different methods of facilitating and promoting the discovery of new truths; and can be most extensively diffused among men by means of the press.

8. To effect the greatest amount of good, the organization should be such as to enable the Institution to produce results, in the way of increasing and diffusing knowledge, which cannot be produced either at all or so efficiently by the existing institutions in our country.

9. The organization should also be such as can be adopted provisionally, can be easily reduced to practice, receive modifications, or be abandoned, in whole or in part, without a sacrifice of the funds.

10. In order to compensate, in some measure, for the loss of time occasioned by the delay of eight years in establishing the Institution,

a considerable portion of the interest which has accrued should be added to the principal.

11. In proportion to the wide field of knowledge to be cultivated, the funds are small. Economy should therefore be consulted in the construction of the building; and not only the first cost of the edifice should be considered, but also the continual expense of keeping it in repair, and of the support of the establishment necessarily connected with it. There should also be but few individuals permanently supported by the Institution.

12. The plan and dimensions of the building should be determined by the plan of the organization, and not the converse.

13. It should be recollected that mankind in general are to be benefited by the bequest, and that, therefore, all unnecessary expenditure on local objects would be a perversion of the trust.

14. Besides the foregoing considerations, deduced immediately from the will of Smithson, regard must be had to certain requirements of the act of Congress establishing the Institution. These are, a library, a museum, and a gallery of art, with a building on a liberal scale to contain them.

SECTION I.

Plan of Organization of the Institution in accordance with the foregoing deductions from the Will of Smithson.

To Increase Knowledge. It is proposed—

1. To stimulate men of talent to make original researches, by offering suitable rewards for memoirs containing new truths; and,

2. To appropriate annually a portion of the income for particular researches, under the direction of suitable persons.

To Diffuse Knowledge. It is proposed—

1. To publish a series of periodical reports on the progress of the different branches of knowledge; and,

2. To publish occasionally separate treatises on subjects of general interest.

DETAILS OF THE PLAN TO INCREASE KNOWLEDGE.

I. *By stimulating researches.*

1. Facilities afforded for the production of original memoirs on all branches of knowledge.

2. The memoirs thus obtained to be published in a series of volumes, in a quarto form, and entitled Smithsonian Contributions to Knowledge.

3. No memoir, on subjects of physical science, to be accepted for publication, which does not furnish a positive addition to human knowledge, resting on original research; and all unverified speculations to be rejected.

4. Each memoir presented to the Institution to be submitted for examination to a commission of persons of reputation for learning in

the branch to which the memoir pertains; and to be accepted for publication only in case the report of this commission is favorable.

5. The commission to be chosen by the officers of the Institution, and the name of the author, as far as practicable, concealed, unless a favorable decision be made.

6. The volumes of the memoirs to be exchanged for the Transactions of literary and scientific societies, and copies to be given to all the colleges, and principal libraries, in this country. One part of the remaining copies may be offered for sale; and the other carefully preserved, to form complete sets of the work, to supply the demand from new institutions.

7. An abstract, or popular account, of the contents of these memoirs to be given to the public through the annual report of the Regents to Congress.

II. *By appropriating a part of the income, annually, to special objects of research, under the direction of suitable persons.*

1. The objects, and the amount appropriated, to be recommended by counsellors of the Institution.

2. Appropriations in different years to different objects; so that in course of time each branch of knowledge may receive a share.

3. The results obtained from these appropriations to be published, with the memoirs before mentioned, in the volumes of the Smithsonian Contributions to Knowledge.

4. Examples of objects for which appropriations may be made.

(1.) System of extended meteorological observations for solving the problem of American storms.

(2.) Explorations in descriptive natural history, and geological, magnetical, and topographical surveys, to collect materials for the formation of a Physical Atlas of the United States.

(3.) Solution of experimental problems, such as a new determination of the weight of the earth, of the velocity of electricity, and of light; chemical analyses of soils and plants; collection and publication of scientific facts, accumulated in the offices of government.

(4.) Institution of statistical inquiries with reference to physical, moral, and political subjects.

(5.) Historical researches, and accurate surveys of places celebrated in American history.

(6.) Ethnological researches, particularly with reference to the different races of men in North America; also, explorations and accurate surveys of the mounds and other remains of the ancient people of our country.

DETAILS OF THE PLAN FOR DIFFUSING KNOWLEDGE

I. *By the publication of a series of reports, giving an account of the new discoveries in science, and of the changes made from year to year in all branches of knowledge not strictly professional.*

1. These reports will diffuse a kind of knowledge generally interesting, but which, at present, is inaccessible to the public. Some

of the reports may be published annually, others at longer intervals, as the income of the Institution or the changes in the branches of knowledge may indicate.

2. The reports are to be prepared by collaborators, eminent in the different branches of knowledge.

3. Each collaborator to be furnished with the journals and publications, domestic and foreign, necessary to the compilation of his report; to be paid a certain sum for his labors, and to be named on the title-page of the report.

4. The reports to be published in separate parts, so that persons interested in a particular branch can procure the parts relating to it without purchasing the whole.

5. These reports may be presented to Congress, for partial distribution, the remaining copies to be given to literary and scientific institutions, and sold to individuals for a moderate price.

The following are some of the subjects which may be embraced in the reports:*

I. PHYSICAL CLASS.

1. Physics, including astronomy, natural philosophy, chemistry, and meteorology.
2. Natural History, including botany, zoology, geology, &c.
3. Agriculture.
4. Application of science to arts.

II. MORAL AND POLITICAL CLASS.

5. Ethnology, including particular history, comparative philology, antiquities, &c.
6. Statistics and political economy.
7. Mental and moral philosophy.
8. A survey of the political events of the world; penal reform, &c.

III. LITERATURE AND THE FINE ARTS.

9. Modern literature.
10. The fine arts, and their application to the useful arts.
11. Bibliography.
12. Obituary notices of distinguished individuals.

II. *By the publication of separate treatises on subjects of general interest.*

1. These treatises may occasionally consist of valuable memoirs translated from foreign languages, or of articles prepared under the direction of the Institution, or procured by offering premiums for the best exposition of a given subject.

2. The treatises should, in all cases, be submitted to a commission of competent judges, previous to their publication.

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* This part of the plan has been but partially carried out.

3. As examples of these treatises, expositions may be obtained of the present state of the several branches of knowledge mentioned in the table of reports.

SECTION II.

Plan of organization, in accordance with the terms of the resolutions of the Board of Regents providing for the two modes of increasing and diffusing knowledge.

1. The act of Congress establishing the Institution contemplated the formation of a library and a museum; and the Board of Regents, including these objects in the plan of organization, resolved to divide the income* into two equal parts.

2. One part to be appropriated to increase and diffuse knowledge by means of publications and researches, agreeably to the scheme before given. The other part to be appropriated to the formation of a library and a collection of objects of nature and of art.

3. These two plans are not incompatible with one another.

4. To carry out the plan before described, a library will be required, consisting, 1st, of a complete collection of the transactions and proceedings of all the learned societies in the world; 2d, of the more important current periodical publications, and other works necessary in preparing the periodical reports.

5. The Institution should make special collections, particularly of objects to illustrate and verify its own publications.

6. Also, a collection of instruments of research in all branches of experimental science.

7. With reference to the collection of books, other than those mentioned above, catalogues of all the different libraries in the United States should be procured, in order that the valuable books first purchased may be such as are not to be found in the United States.

8. Also, catalogues of memoirs, and of books and other materials, should be collected for rendering the Institution a centre of bibliographical knowledge, whence the student may be directed to any work which he may require.

9. It is believed that the collections in natural history will increase by donation as rapidly as the income of the Institution can make provision for their reception, and, therefore, it will seldom be necessary to purchase articles of this kind.

10. Attempts should be made to procure for the gallery of art, casts of the most celebrated articles of ancient and modern sculpture.

11. The arts may be encouraged by providing a room, free of expense, for the exhibition of the objects of the Art-Union and other similar societies.

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* The amount of the Smithsonian bequest received into the Treasury of the United States is	$515,169 00
Interest on the same to July 1, 1846, (devoted to the erection of the building,)	242,129 00
Annual income from the bequest	30,910 14

12. A small appropriation should annually be made for models of antiquities, such as those of the remains of ancient temples, &c.

13. For the present, or until the building is fully completed, besides the Secretary, no permanent assistant will be required, except one, to act as librarian.

14. The Secretary, by the law of Congress, is alone responsible to the Regents. He shall take charge of the building and property, keep a record of proceedings, discharge the duties of librarian and keeper of the museum, and may, with the consent of the Regents, *employ assistants.*

15. The Secretary and his assistants, during the session of Congress, will be required to illustrate new discoveries in science, and to exhibit new objects of art; distinguished individuals should also be invited to give lectures on subjects of general interest.

This programme, which was at first adopted provisionally, has become the settled policy of the Institution. The only material change is that expressed by the following resolutions, adopted January 15, 1855, viz:

Resolved, That the 7th resolution passed by the Board of Regents, on the 26th of January, 1847, requiring an equal division of the income between the active operations and the museum and library, when the buildings are completed, be and it is hereby repealed.

Resolved, That hereafter the annual appropriations shall be apportioned specifically among the different objects and operations of the Institution, in such manner as may, in the judgment of the Regents, be necessary and proper for each, according to its intrinsic importance, and a compliance in good faith with the law.

REPORT OF THE SECRETARY.

To the Board of Regents of the Smithsonian Institution:

Gentlemen: The year which has elapsed since the last meeting of the Board of Regents has been marked by events which must have a decided influence on the future history of the establishment intrusted to your care. The plan of organization adopted, and the operations in accordance with it, have been widely discussed by the public. The subject has also been brought before Congress, and referred to a special committee of the House of Representatives, and to the Judiciary Committee of the Senate. The committee of the House had not time, before the close of the session, to visit the Institution, or to make such an examination of the management and the condition of its affairs as the importance of the matter referred to them would seem to demand. The members were divided in opinion as to the question of further legislation, and no action was taken upon the reports which they presented. The Judiciary Committee of the Senate reported on the subject, and unanimously approved the acts of the Regents in construing the law of Congress, in interpreting the will of Smithson, and in what they had done in the way of increasing and diffusing knowledge among men.

The discussions that have taken place in the journals of the day in regard to the policy pursued by the Institution, together with the printing of an extra number of copies of the Regents' report to Congress, have given the public generally an opportunity of becoming more fully acquainted than heretofore with the character of the trust, and the manner in which it has been administered. From the number of letters received during the past year, containing spontaneous expressions of opinion relative to the course pursued by the Regents, there can be no doubt that the policy which has been adopted is the one most in accordance with the views of a majority of the intelligent part of the community.

It is not contended that the plan of organization is in all respects what could be wished; on the contrary, it is believed that more of the income is devoted to local objects—in the support of a large building and the expensive establishment necessarily connected with it—than is entirely consistent with a proper interpretation of the will of Smithson. But in establishing an institution in which various opinions were to be regarded, the question was not, what, in the abstract, was the best system, but the best which, under the circumstances, could be adopted. It can hardly be expected that any plan, however faithfully and cautiously pursued, will give general, not to say universal, satisfaction. In the faithful discharge of their duty, the directors of the Institution are liable, frequently, to make decisions which conflict with what is deemed, the interests of individuals; and when propositions intended only for personal advantage are rejected, a hostile feeling is sometimes engendered, which finds vent in misrepresentation and public attacks. After due caution has been observed in order to give no just cause of complaint, such attacks should be disregarded. The Regents will, doubtless, adhere to the line of policy which has been adopted; turn neither to the right nor to the left to catch an apparently favorable breath of popular applause, and continue to *lead*, rather than *follow*, public opinion. The directors of the establishment, whose duty it is to make all that concerns it their special study, ought to be better acquainted with the intentions of the donor, and the results produced by the expenditure of the income of his bequest, than those who have no responsibility of this kind to induce that attention to its affairs which could alone qualify them to become proper advisers as to its operations.

Since the last meeting of the Board, the Institution has not only sustained, but has extended the reputation it had previously acquired. The number of applications on favorable terms, even in a commercial point of view, which have been made from abroad for the Smithsonian publications, has very much increased, and the number of volumes received in exchange has exceeded that of any previous year. The inquiries which have been made of the Institution for information in regard to different branches of knowledge, the references to it for the decision of important questions, and the applications for assistance in the prosecution of original research, indicate an extending field of usefulness open to its cultivation. Indeed, so many objects of the highest importance are presented, that much difficulty would be experienced in the selection of those which should first receive attention, if the directors were not governed by fixed rules. The tendency to expand the operations of the Institution beyond its means, enforces the necessity of constant vigilance and forethought. While much may be done in the way of advancing knowledge by the judicious application of a small fund, it is surprising that so much is expected to be accomplished by an income so limited as that of this bequest, and that propositions should frequently be made to the Regents by intelligent persons to embark in enterprises which would involve the expenditure of the whole annual interest on a single object.

The building is at length completed, and its several apartments are now in a condition to be applied to the uses of the Institution. As various changes have been made in the original plan, the following brief description may not be inappropriate at this time. It consists of a main edifice, two wings, two connecting ranges, four large projecting towers, and several smaller ones. Its extreme length from east to west is 447 feet, with a breadth varying from 49 feet to 160 feet. The interior of the east wing is separated into two stories, the upper of which is divided into a suite of rooms for the accommodation of the family of the Secretary; the lower story principally comprises a large single room, at present appropriated to the storage of publications and the reception and distribution of books connected with the system of exchange. The upper story of the eastern connecting range is divided into a number of small apartments devoted to the operations in natural history, and the lower story is fitted up as a working laboratory.

The interior of the main edifice is 200 feet long by 50 feet wide, and consists of two stories and a basement. The upper story is divided into a lecture-room capable of holding 2,000 persons; and into two additional rooms, one on either side, each fifty feet square, one of which is appropriated to a museum of apparatus, and the other, at present, to a gallery of art. Both are occasionally used as minor lecture-rooms and for the meetings of scientific, educational, or industrial associations. The lower story of the main building consists of one large hall to be appropriated to a museum or a library. It is at present unoccupied, but will be brought into use as soon as the means are provided for furnishing it with proper cases for containing the objects to which it may be appropriated. The basement of this portion of the building is used as a lumber-room and as a receptacle for fuel.

The west wing is at present occupied as a library, and is sufficiently large to accommodate all the books which will probably be received during the next ten years. The west connecting range is appropriated to a reading-room.

The principal towers are divided into stories, and thus furnish a large number of rooms of different sizes, which will all come into use in the varied operations of the Institution. A large room in the main south tower is appropriated to the meetings of the "Establishment" and the Board of Regents; three rooms in one range, in the main front towers, are used as offices; and two rooms below, in the same towers, are occupied by one of the assistants and the janitor; other rooms in the towers are used for drawing, engraving, and work-shops. There are in the whole building, of all sizes, ninety different apartments; of these eight are of a large size, and are intended for public exhibitions.

The delay in finishing the building has not only been attended with advantage in husbanding the funds, but also in allowing a more complete adaptation of the interior to the purposes of the Institution. It is surely better, in the construction of such an edifice, to imitate the example of the mollusc, who, in fashioning his shell, adapts it to the form and dimensions of his body, rather than that of another animal who forces himself into a house intended for a different occupant. The first point to be settled, in commencing a building, is the uses to which it is to be applied. This, however, could not be definitely ascertained at the beginning of the Institution, and hence the next wisest step to that of not commencing to build immediately, was to defer the completion of the structure until the plan of operations and the wants of the establishment were more precisely known.

From the report of the Building Committee it will appear that about $6,000 remain to be paid upon the contracts, which amount will be met by the interest of the extra fund during the present year. The whole amount expended on the building, grounds, and objects connected with them, is $318,727 01. This exceeds considerably the original estimate, and the limit which was at first adopted by the Regents.

The excess has been principally occasioned by substituting fire-proof materials for the interior of the main building, instead of wood and plaster, which were originally intended.

It is to be regretted that a design so costly was adopted; but the law of Congress evidently contemplated an expensive building, and placed no restriction on the Regents as to cost or plan, except the preservation of the principal of the bequest.

From the report of the Executive Committee it will be seen that not only has this restriction been observed, but that, notwithstanding the enhanced expenditure, a considerable augmentation of the fund has been effected. The original $515,000, received from the bequest of Smithson, is still in the treasury of the United States; and, after the present debt on the building shall have been discharged, there will remain in the hands of the treasurer the sum of $125,000 of unexpended interest. Though this is a favorable condition of the finances, yet caution in the expenditure is still imperatively required. We should not forget that the ordinary expenses of the Institution have constantly increased; and that, whilst the nominal income has remained the same, the value of money has depreciated; and, consequently, the capability of the original bequest to produce results has been abridged in a corresponding proportion. Besides, when the building is entirely occupied, the expense of warming, attendance, &c., must necessarily be much increased beyond its present amount. The repairs, on account of the peculiar style of architecture adopted, will ever be a heavy item of expenditure. The several pinnacles, buttresses, and intersecting roofs, all afford points of peculiar exposure to the injuries of the weather. In this connexion, I cannot help again expressing the hope that Congress will, in due time, relieve the Institution from the support of this building, and that it will ultimately appropriate at least the greater part of it to a national museum, for the general accommodation of all the specimens of natural history and of art, which are now accumulating in the Capital of the nation. The two wings and connecting ranges would be quite sufficient for all the operations of the Institution, and a large portion of the funds now absorbed in the incidental expenses, which have been mentioned, could be devoted to the more legitimate objects of the bequest.

It was mentioned in a previous report that the rooms of the upper story of the building were particularly arranged with a view to accommodate the meetings of literary, scientific, and other associations which might assemble at the seat of government. During the past year the following societies have availed themselves of the facilities thus afforded, viz: the United States Agricultural Society, the Metropolitan Mechanics' Institute, a musical convention of the choirs in this city and of persons invited from a distance, also a second convention under the auspices of the Philharmonic Society of Washington. Besides these, the Teachers' Association of the District of Columbia has held its monthly meetings in this building, and the rooms have been frequently occupied during a single evening for public purposes. The use of the lecture-room is granted when the object for which it is asked is of general public utility, and not of a party or sectarian character, or intended to promote merely individual interests.

Since the death of the lamented Downing, but little has been done to complete the general plan of the improvement of the mall proposed by him and adopted by Congress. An annual appropriation, however, has been made for keeping in order the lot on which the Smithsonian building is situated, and it is hoped that in due time the whole reservation from the Capitol to the Washington Monument will, in accordance with the original design, be converted into an extended park.

The Smithsonian building having been completed, the refuse material will be removed from the south part of the lot, and the whole grounds around the institution will then be in a condition for permanent improvement. It is to be regretted that Congress has not made an appropriation to carry out the suggestion of Dr. Torrey, and other botanists, of establishing here an arboretum to exhibit the various ornamental trees of indigenous growth in this country. The climate of Washington is favorable to the growth of a very large number of the products of our forests, and an exhibition of this kind would serve to render better known our botanical wealth, and to improve the public taste. The preservation and cultivation of our native trees are objects of national importance.

A subscription has been collected by the members of the American Pomological Society for the erection of a monument to the memory of Downing, and the President has given his consent to the placing of this in the same lot with the Smithsonian Institution. The monument will be erected in the course of the present year, and will serve to perpetuate the memory of a public benefactor, as well as to embellish the grounds.

Publications.—Since the last meeting of the Board of Regents, the seventh volume of the Smithsonian Contributions to Knowledge has been printed and distributed. Owing to certain changes, which were considered desirable in some of the memoirs mentioned in the last report, they were not ready in time for the press, and this volume was consequently made up without them. It therefore does not contain as many pages of printed matter as some of the previous volumes. It has, however, a larger number of plates, and consequently the expense of its publication has been equal to that of any of the preceding ones.

1. Among the papers mentioned in the last report was one by Mr. S. F. Haven, librarian of the American Antiquarian Society, on the progress of information and opinion respecting the archæology of the United States. The printing of this paper, which is now nearly completed, was delayed for the purpose of enabling the author to extend it in some particulars, and to include in it a more definite account of some branches of ethnological investigation than was at first contemplated. It will be recollected that the object of this paper is, first, to present the speculative opinions relative to American antiquities, which preceded any systematic or scientific investigation, and to exhibit the various hypotheses advanced, as to their origin, based upon hints from sacred or profane history; secondly, to follow the steps of inquiry, nearly in the order of time, and to present a summary of facts supposed to be developed, and views entertained at different stages of research and discovery. When the author, in pursuing his subject, arrived at the consideration of the period when philological and physiological deduc-

tions, from reliable information, were specially and scientifically brought to bear upon this investigation, it seemed necessary to enlarge the original plan, and to exhibit, concisely, the considerations involved in the discussions, the course they had taken in this country, and the conclusions to which different writers in these departments of research had been led.

The last chapter will present a sketch of what appears to be the actual information now possessed respecting the vestiges of antiquity in the United States, and will include the consideration of the following points:

1st. To what places of the American continent the known courses of the winds and currents might casually bring the vessels of ancient navigators.

2d. The evidences of foreign communication said to be observable at those places.

3d. The other known means of access from foreign countries.

4th. The topography of ancient remains in the United States.

5th. The external character of those remains.

6th. Their local peculiarities.

7th. The character of the articles taken from them, and supposed to be of contemporaneous origin.

8th. The inscriptions, medals, and other remains, supposed to indicate the use of letters or hieroglyphic symbols.

This paper, as usual, will be issued, at first, separately, and afterwards published as a part of the eighth volume of Contributions.

2. The paper mentioned in the last report, on the Tangencies of Circles and Spheres, by Major Alvord, of the United States army, has been printed, and is now ready for distribution. It is due to Professors Church and Gibbes, to whom the memoir was submitted, to mention that they have given it critical examination, have suggested several improvements, which have been adopted by the author, and that, in his absence on official duty in Oregon, they have read the proof-sheets, and corrected the plates and text—a service of no small moment in the publication of an abstruse mathematical paper, in which extreme precision, if not absolute accuracy of typography, is required.

3. The paper on the Aurora Borealis, by Professor Olmsted, described in the last report, has also received some emendations, and is now in the press. The valuable collection of notices of the appearances of the aurora in northern latitudes, by Peter Force, Esq., of Washington, is also in the hands of the printer, and will form an appendix to the eighth volume.

4. A corrected edition of the first part of the tables for facilitating the investigation of physical problems, mentioned in the fifth and sixth reports, has been prepared, and, with the second part of the same series, is now in the press. No publications of the Institution have been called for more frequently than these tables. They have been introduced into Great Britain, and have supplied a want which has long been felt by the practical cultivator of physical science in that country, as well as our own.

Each set of tables has a distinct title and paging, and may be separately stitched and distributed in a pamphlet form, or bound together in a single octavo volume. The following is the list of the tables: 1. Comparison of the thermometrical scales; 2. A series of hygrometrical tables; 3. Tables for comparing the quantities of rain; 4. A series of tables for comparison of different barometrical scales, &c.; 5. Tables for computing differences of level by means of the barometer; 6. To ascertain elevations by the boiling-point of water; 7. For the conversion of different measures of length.

A full descriptive list will be found in the appendix.

In connexion with the publication of these tables, I may allude to the fact which is constantly to be regretted, that, while the characters which indicate the numerals of ordinary and scientific computation are the same in all civilized countries, there should exist, in this age of the world, such a diversity in the standards and divisions of measures. The present appears to be an auspicious moment for attempting to introduce a uniform system of weights and measures. This would probably present no great difficulty in the case between Great Britain and this country, and since England and France are now allied in a common cause, they might both be induced to agree upon a general standard; and if this were adopted by all who speak the English and French languages, it would soon become common to every part of the civilized world.

5. Another paper submitted for publication is on a special branch of natural history, called Oology. The design of this memoir is to give, by means of colored engravings, correct representations of the eggs of the birds of North America, so far as they have been ascertained, and to accompany each figure with an account of whatever may be known as to the mode of breeding, the construction of the nests, and the geographical distribution of the species during the hatching season. It is believed that this paper will supply a deficiency in the natural history of North America. There is no separate treatise on its öology, nor do any of the works on American ornithology furnish reliable descriptions under this head, except in regard to a few of the more common birds. All our ornithologists, says the author, Audubon not excepted, have given their attention almost exclusively to the birds, and have omitted to notice the peculiarities of their propagation. The reason for this may readily be found in the difficulty attending the investigation, which is to be appreciated only by those who have sought to make a study of this branch of natural history. The author has devoted to this subject all the leisure he could spare during twenty years, and each year he has been able to add new contributions to the stock of knowledge, as well as illustrations and specimens to the common store, until he is now enabled to describe and figure at least four-fifths of the oology of this continent.

In the commencement of the operations of the Institution, the Regents might have hesitated to sanction the publication of a paper on a subject which at first sight would appear to be so far removed from practical application. But it is believed that since that period, more just views of the importance of such subjects have become prevalent, and that the Smithsonian publications themselves have done good service in diffusing more liberal sentiments. Indeed, it is an important part of the duty of this Institution to encourage special lines of research into every department of the varied domain of nature. Though it might be a perversion of intellect for a large number of persons in the same country to occupy themselves in any one pursuit of this kind, when so much on every hand is required to be done, yet it is highly meritorious in any individual to devote himself systematically, industriously, and continuously, for years, to the elucidation of a single subject. He may be said to resemble in this respect the explorer of an inhospitable region, who enables the world to see through his eyes the objects of wonder and interest which would otherwise be forever withdrawn from human knowledge. Let censure or ridicule fall elsewhere—on those whose lives are passed without labor and without object; but let praise and honor be bestowed on him who seeks with unwearied patience to develop the order, harmony, and beauty of even the smallest part of God's creation. A life devoted exclusively to the study of a single insect, is not spent in vain. No animal, however insignificant, is isolated; it forms a part of the great system of nature, and is governed by the same general laws which control the most prominent beings of the organic world.

It is proposed to publish this paper in a number of parts, commencing with the oology of the birds of prey. This is one of the most difficult of all the families to study with precision, on account of the retiring habits of the birds and their almost inaccessible breeding places.

6. The next paper is on the relative intensity of the light and heat of the sun upon the different latitudes of the earth, by L. W. Meech, Esq. This memoir, which was submitted for examination to Prof. Peirce and Dr. B. A. Gould, of Cambridge, presents a thorough mathematical investigation of the only known astronomical element of meteorology. It gives a distinct, precise, and condensed view of this element; enables the practical meteorologist to compare it with the results of observation; to eliminate its influence and obtain the residual phenomena in a separated form and better fitted for independent investigation. It determines, from the apparent course of the sun, the relative number of heating and illuminating rays which fall upon any part of the earth's surface. The rays of light and heat from the sun to the earth, though imperceptible in their passage through free space, and manifest only by their results at the surface of the globe, evidently constitute a primary element of meteorology. The subsequent effects ,which are measured by the thermometer and designated by the word *temperature*, are secondary, and modified by a variety of proximate causes. In accordance with this distinction, the numerous researches in this field may be divided into two classes, namely, those which relate to the number of rays falling on a given place, and those which relate to the temperature produced by these rays under different conditions of surface, &c. To the former of these belongs the investigation of Halley, given in the Philosophical Transactions for 1693. By regarding heat as of the nature of force and resolving it into a horizontal and a vertical component, he drew the proper distinction between the number of rays and their heating effect or "impulse," which is expressed in the well known law, that the sun's intensity at

any time is proportional to the sine of the sun's altitude above the horizon. The subject was also investigated by Euler in 1739, in the Petersburg Commentaries, with some improvements upon the method of Halley, but owing to the introduction of false hypotheses, it was not brought to a successful conclusion. More recently, Fourrier and Poisson have discussed the problems of terrestrial heat at great length, but in so general a way as to leave very much yet to be accomplished.

The present memoir, avoiding hypotheses, proceeds entirely in accordance with the principle that the intensity of the heat and light radiated from the sun to the earth, is inversely proportional to the square of the distance. By strict adherence to this primary law, the principles of the astronomical branch of meteorology are deduced in a connected series with geometrical precision, while at the same time an account is taken of all the modifying circumstances of which the effects are definitely known, such as the geographic latitude, the changes of the sun's distance from the earth, the changes of the sun's altitude or oblique direction of the solar beams, and changes in the length of the day.

Among the more interesting results thus obtained are the simple expressions for annual intensity and the duration of sunlight and twilight, and a more full delineation of the peculiar increase of summer heat around the poles, first pointed out by Halley.

The secular changes of solar heat, or those which relate to long periods, are also analyzed in accordance with the received variations of astronomical elements, particularly those given by Leverrier, and extended to very remote epochs. This part of the investigation is intimately connected with the geology of the globe, and the question as to the amelioration of the climate of America since the period of our colonial history. The paper is accompanied by a number of graphical illustrations, which, besides exhibiting the general results, show the reflex agency of the earth and its atmosphere in modifying the direct heat of the sun, and the progressive change of climates, and the seasons of the year. A small appropriation was made to defray the expense of the arithmetical calculations necessary for deducing the numerical values from the general formula.

7. In a previous report it was stated that a small appropriation had been made to defray, in part, the expense of some special geological explorations, under the direction of Professor E. Hitchcock, of Amherst College, Massachusetts. The papers containing the result of these investigations have been presented to the Institution for publication. They all relate to surface geology, or the geological changes which have taken place on the earth's surface since the tertiary period.

The first paper treats of the unconsolidated terraces, beaches, submarine ridges, &c., that have been formed along the shores of the ocean, lakes, and rivers, since the last submergence of the continents. The author has given the heights of a great number of these above the ocean, and the rivers, and a map of those in the valley of the Connecticut river. The evidence they afford of a submergence of this continent, at least, and a part of Europe, since the Drift Period, is regarded by the author as one of his most important conclusions. But many others, however, are presented, which will tend to modify the opinions entertained of the superficial deposits of the globe.

The second paper is on the erosions of the surface of the earth, especially by rivers. Of this phenomenon numerous examples are given, and those described minutely which have fallen under the author's own observations. Some of the conclusions to which he has been conducted are new and unexpected. He has, for instance, pointed out several traces of old river-beds, now filled up and abandoned, through which, in his opinion, the streams ran on a former continent.

The third paper would appear to establish the fact that glaciers once existed on some of the mountains of New England, in distinction from the drift agency, which he regards as chiefly the result of icebergs and oceanic currents. This paper is accompanied by a map of the ancient glaciers, so that geologists can examine for themselves the data from which the deductions are made.

These investigations, says the author, "are an humble attempt to penetrate a little distance into the obscurities of surface geology, and to exhibit changes which seem to have been more overlooked than any other which the earth has undergone." Whatever may be the opinions entertained of the conclusions of the author, the facts which he has collected must ever be of importance.

On account of the colored maps which are necessary to illustrate these papers, their expense will be considerable, and we shall be obliged, perhaps, to defer their publication until towards the close of the present year.

It is a subject of congratulation, and an evidence of the advance of liberal sentiments in regard to the importance of abstract science in our country, that within the last few years liberal donations have been made for the publication of original research and the promotion of original scientific investigations. In addition to the $100,000 bequeathed some years since to the Harvard Observatory, the same establishment has lately received from the Hon. Josiah Quincy the sum of $10,000 for the publication of its observations; and $10,000 has been bequeathed by Mr. Appleton for the publication of original memoirs in the Transactions of the American Academy. A wealthy lady of the city of Albany has just reared a monument to the memory of her husband in the establishment of an observatory, which, we trust, will be more enduring than any merely material edifice, however permanent and unalterable may be its character. Discoveries will undoubtedly be made by means of this enlightened bequest, which will indelibly associate the name of Dudley with the future history of astronomy. The love of posthumous fame is a natural and laudable desire of the human mind. It is an instinct, as it were, of immortality, which should be fostered and kept alive by example as one of the most powerful inducements to enlightened benevolence. And what prouder monument could be coveted than that which shall associate a name with the discovery of truths, the knowledge of which will be as widely extended and as continuous in duration as civilization itself? Smithson was ambitious of this distinction, and has presented with rare sagacity, to all who have the means of gratifying the same feeling, a noble example. In connexion with the same subject, I may refer to the unexampled provision which has been made by subscription for the publication of the extended researches of Prof. Agassiz. The results of these researches are to be comprised in ten quarto volumes, at a subscription price of $120. The whole number of subscribers already obtained is three thousand, which will produce $360,000. The Smithsonian Institution had commenced the preparation of the plates of several memoirs by Prof. Agassiz, which will now be probably merged in this work; and thus, though it may lose the honor of a more permanent association of the name of this celebrated individual with its own publications, yet a portion of its funds will thus be set free for the publication of the researches of less fortunate though meritorious laborers in the field of knowledge. The Institution, however, will have largely contributed from its museum to the materials which will be required in the preparation of this great work, and will thus be still connected with this important enterprise.

Exchanges.—The system of scientific and literary exchanges, of which an account has been given in the previous reports, has become more widely known and its advantages more generally appreciated. Nearly all the exchanges of scientific works between societies and individuals in this country and abroad are now made through the agency of this Institution. The whole number of articles transmitted during the year 1855 was 8,585. The whole number of separate articles received during the same time cannot be stated, as those addressed to particular persons or societies were enclosed in packages which were not opened. The articles received in behalf of the Institution amounted to 4,500, and the number of packages for other parties to 1,445. The latter, in almost every case, contained several different works, which would swell the amount received to a larger number than that which was sent. The associations in this country which have availed themselves of the facilities of the system comprise nearly all those that publish Transactions. Among these are many of the agricultural societies of the western States. In a number of cases societies and individuals have transmitted sets of their works, to be distributed by the Institution to such associations as it might deem best entitled to receive them.

The Smithsonian agency is not confined to the transmission of works from the United States, but is extended to those from Canada, South and Central America, and in its foreign relations embraces every part of the civilized world. It is a ground of just congratulation to the Regents, that the Institution, by means of this part of the plan of its organization, is able to do so much towards the advance of knowledge. It brings into friendly correspondence cultivators of original research the most widely separated, and emphatically realizes the idea of Smithson himself, that "the man of science is of no country;" that "the world is his country, and all mankind his countrymen."

The system of exchange has found favor with foreign governments, and the Smithsonian packages are now admitted into all ports to which they are sent, without detention, and free of duty. It has also been highly favored by the liberal aid of companies and individuals in this country. The mail steamship line to California via Panama conveys our packages free of cost to the Pacific coast. The line of steamers to Bremen has also adopted a like liberal policy, and Messrs. Oelrichs & Lurman, of Baltimore, have indicated their estimation of the value of the system, by making no charge whatsoever for transmitting a large number of boxes to Germany, and in receiving and forwarding others from that country.

In connexion with the subject of exchanges, it becomes my duty to announce the loss which the Institution has experienced in the death of one of its warmest friends and most active agents, Dr. J. G. Flügel, of Leipsic. After a residence of several years in this country he returned to Germany as United States consul, in which capacity he was unremitting in his efforts to render service to American travellers, and, by his untiring industry and zeal in behalf of the Institution, contributed more than any other person to make it known through northern and central Europe. His son, Dr. Felix Flügel, has been appointed his successor, and has evinced a desire and given evidence of his ability to carry on the system with promptness and efficiency. The agent of the Institution in London is Mr. Henry Stevens, and in Paris Mr. Hector Bossange; and to these gentlemen the thanks of the Regents are due for important services in the distribution and reception of packages without charge.

Correspondence.—The correspondence during the last year has been more extended than that of any preceding period. The character of the Institution becoming more widely known, the number of applications for information relative to particular branches of knowledge has been increased. The correspondence relates to the exchanges, the collections, the publications, the communication with authors and the members of commissions to which memoirs are submitted, answers to questions on different branches of knowledge, and reports as to the character of specimens of natural history, geology, &c.; also explanations of the character of the Institution, the distribution of its publications, its system of meteorology, &c.

The whole number of pages copied into letter-books in 1855 is about 4,000.

Besides this correspondence, there have been sent off from the Institution upwards of 5,000 acknowledgments of books and other articles presented to the Institution, and 6,000 circulars, asking for information on special points, such as natural history, meteorology, physical geography, statistics of libraries and colleges, &c.

Many of the communications are interesting additions to knowledge, though they are scarcely of a character to warrant their publication in the quarto series of Contributions; and it is now proposed to append some of these to the annual report to Congress to illustrate the operations of the Institution, as well as to furnish information on subjects of interest to the public. The meteorological system gives rise to an extensive correspondence, and maintains a lively sympathy between the institution and a large number of intelligent individuals. During the past year, as usual, many crude speculations on scientific and philosophical subjects have been presented for critical examination. To these, in all cases, respectful answers have been returned, and an endeavor has been made to impress upon the correspondent the *distinction between fanciful speculation and definite scientific investigation.*

Education.—The plan of organization of this Institution does not include the application of any of its funds directly to educational purposes. Were the whole Smithsonian income applied to this one object, but little, comparatively, of importance could be effected, and that little would scarcely be in accordance with the liberal intention of the testator, as expressed in his will, by the terms "the increase and diffusion of knowledge among men." Still, the theory and art of education are susceptible of improvement, as well as of a wider application; and therefore, though the Institution may not attempt to do anything itself in the way of elementary instruction, it may, in accordance with its plan of operations, assist in diffusing a knowledge of the progress of the art of teaching, and of its application in this country.

At a meeting of the American Association for the Advancement of Education, held in this building in December, 1854, a committee was appointed, which called the attention of the Institution to the importance of aiding in preparing and publishing a history of education in the several States of the Union, the object of which would be to diffuse a knowledge of what has been done in each section of the country among all the others, and thus to render the separate experience of each beneficial to the whole. After consultation with the members of the Executive Committee, then in the city, it was concluded to devote $350 to this purpose. This sum has accordingly been advanced to the Hon. Henry Barnard, of Connecticut, who has collected and digested for publication the materials for a work of this kind.

The subject will be presented under the following heads:

1. Survey of the principal agencies which determine the education of a people, with an explanation of the American nomenclature of schools and education.
2. A brief sketch of the action of the general government in the matter of education and schools.
3. Legislation of each State respecting education.
4. Condition of education in each State, according to the census returns of 1850, and other reliable sources of information.
5. Educational funds—State, municipal, and institutional.
6. Educational buildings: remarks on their general condition, with illustrations of a few of the best specimens of each class of buildings.
7. Catalogue of documents relating to the educational systems and institutions in each State.
8. Statistical tables, with a summary of educational agencies, such as the press, ecclesiastical organizations, facilities of locomotion, &c.
9. A brief statement of the educational systems and statistics of the most civilized countries of Europe.

The work will either be published as a separate report on education, or may be given in a series of numbers of the American Journal of Education, extra copies of which will be obtained for distribution.

It is believed that this exposition of the subject will supply a deficiency which has long been felt, and be of much service in advancing the important cause to which it relates.

Laboratory, Researches, &c.—The law of Congress incorporating the Institution directed the establishment of a laboratory, and, in accordance with this, a commodious room has been fitted up with the necessary appliances for original research in chemistry and other branches of physical science.

During the past year a number of different researches have been prosecuted in this apartment.

1. A continuation of those mentioned in the last report on building material.
2. A series relating to combustion, and some points on meteorology.
3. On the flow of air through tubes of various forms.
4. On the application of some newly-discovered substances to practical purposes in the arts.
5. The examination of the minerals of the Pacific railroad and other expeditions.

Though the funds of the Institution will not permit the constant employment of a practical chemist, yet we are enabled to do something towards the support of a person in this line, by referring to him the articles of a commercial value which are submitted to us for examination, and for which the cost of analysis is paid by the parties seeking the information.

A young chemist, who has spent three years in Germany, has now the use of the laboratory, and is prepared to make any analyses which may be required. For the facilities afforded him he is to keep the apparatus in working order, and to make such examinations of specimens as may not require much labor.

In one of the previous reports it was mentioned that a set of instruments for observing the several elements of terrestrial magnetism was lent to Dr. Kane for use in his Arctic explorations, and I am happy to inform the Board that these instruments have done good service to the cause of science in the hands of this intrepid explorer and his assistants, and that they have been returned in good condition. They will be again intrusted to other persons for observations in different parts of this country.

Meteorology.—Since the last meeting of the Board an arrangement has been made with the Commissioner of Patents by which the system of meteorology, established under the direction of the Institution, will be extended, and the results published more fully than the Smithsonian income would allow. A new set of blank forms has been prepared by myself, and widely distributed under the frank of the Patent Office. An appropriation has also been made for the purchase of a large number of rain-gages, to be distributed to different parts of the country, for the purpose of ascertaining more definitely with compared instruments the actual amount of rain which falls in the different sections of our extended domain. A series of experiments has been made with regard to the different form of gages, and a very simple one, which can be manufactured at a small expense, is easy of application, and can be readily transported by mail, has been adopted. Mr. Jas. Green, of New York, has continued to manufacture standard instruments in accordance with the plan adopted by the Institution, and to supply these at a reasonable price to observers. He preserves an accurate record of the comparison of each instrument with the standards furnished by the Institution, and in this way good service is rendered to the advance of this branch of knowledge by the general introduction of compared and reliable instruments. The system is constantly improving in precision and extent.

Complaints have been made that but few of the materials collected by the Institution have yet been published. The answer to these, however, is readily given in the fact that so much of the income up to this time has been devoted to the building, and so many demands have been made upon the Smithsonian funds for objects requiring more immediate attention, that little could be done in this line; and, besides, it is more important that the information should be reliable than that it should be quickly published. The value of observations of this character increases in a higher ratio than the time of their continuance, and, therefore, what may be lost by delay is more than compensated by the precision and value of the results.

The reduction of the meteorological observations has been continued by Professor Coffin during the past year. He has completed the discussion of all the records for 1854, and those of 1855 as far as they have been sent in. The publication of these, however, in full, will require a volume which, we trust, will be printed at the expense of the general government, as an appendix to the Agricultural Report of the Patent Office.

Important additions have lately been made to the physical geography of the western portions of the United States, under the direction of the Secretary of War, by the officers of the army engaged in the explorations of the several routes for a railway to the Pacific. A series of exact barometrical sections has been measured from the Mississippi river to the Pacific ocean. The elevations of the extended plain which constitutes the base of the Rocky mountains and of the parallel ridges have been determined. Temporary meteorological observations have also been made, which afford approximate data relative to the climate of this region.

The elevation and direction of the ridges which separate the valley of the Mississippi from the Pacific ocean have a controlling influence on the climate, particularly on the precipitation of the North American continent, and especially distinguish the storms of the Pacific coast from those of the Atlantic States.

The additions which have been made to the physical geography and natural history of this continent under the enlightened policy of the Secretary of War, will be received with great interest by the scientific men of Europe.

In studying the general physical phenomena of the globe, the western half of the North American continent, in comparison with other parts of the world, has been almost a blank. It is hoped, however, that the spirit of inquiry that has been awakened and the enterprises which have been commenced, and thus far successfully prosecuted in this line, will be continued, and will supply the desiderata which have so long been felt. If all the military posts, or a selection which might be made from them, were furnished with a full set of instruments, and the observations made with due precision, results of the highest interest to the man of science, as well as to the agriculturist, the physician, and the engineer, would be obtained.

As first approximations the simple observations at the different posts, which have thus far been published, are acceptable additions to knowledge; but whatever is worth doing at the expense and under the direction of the general government, ought to be as well done as the state of science and the circumstances under which the work is commenced will admit.

A series of continued observations at a few posts, made at each hour during the twenty-four, similar to those carried on under the direction of Major Mordecai, at the Frankford arsenal, would afford materials of much interest for determining in the interior of the continent the hours of the day most suitable to be chosen for ascertaining the mean temperature, and for reducing the observations made at different times to the same hours, as well as for settling the time of occurrence of the daily periodical changes of the atmosphere.

Besides the collection of meteorological materials relative to the climate of the United States, the Institution has in its possession an extensive series of observations made in Texas and Mexico by Dr. Berlandier. These were placed at our disposal by Lieutenant Couch, who was favorably mentioned in the last report as having made a valuable exploration a few years ago in the southern part of our continent. Portions of this material will be published, from time to time, as an appendix to the Smithsonian Contributions.

I am happy to state to the Board, that the Provincial Parliament has made provision for the establishment of a system of meteorology in Canada, which will co-operate with that of the Institution. The act is in the following words:

"Whereas it is desirable at all seminaries and places of education to direct attention to natural phenomena, and to encourage habits of observation; and whereas a better knowledge of the climate and meteorology of Canada will be serviceable to agricultural and other pursuits, and be of value to scientific inquirers; be it therefore enacted, that it shall be part of the duty of every county grammar school to make the requisite observations for keeping, and to keep a meteorological journal, embracing such observations, and kept according to such form as shall from time to time be directed by the council of public instruction; and all such journals, or abstracts of them, shall be presented annually by the chief superintendent of schools to the governor-general, with his annual report.

"Every county grammar school shall be provided, at the expense of the county, with the following instruments: One barometer, one thermometer for the temperature of the air, one thermometer for evaporation, one rain-gage, one wind-vane."

The Library.—More has been accomplished in the library during the past year than at any previous period. The books have been provisionally arranged according to subjects, and considerable progress made in a full catalogue as well as in an index to the chronological record of the daily reception of books as they are placed in the library. The first part of a descriptive catalogue of the works received in exchange has been published, and the second part is now in process of preparation. An extra number of the first part has been struck off, and copies have been sent in the form of an appendix to the seventh volume of Smithsonian Contributions to Knowledge, to all foreign societies, in order that our deficiencies may be made known, and an appeal made to our contributors for their supply. This list will also be of much importance to persons engaged in original research in this country, since it will give them, in a separate catalogue, a knowledge of the rich collection of Transactions and proceedings of literary and scientific societies in the possession of the Institution.

The value of a library is not to be estimated by the *number* of volumes it contains, but by the character of the books of which it is composed. It is the present intention of the Regents to render the Smithsonian library the most extensive and perfect collection of Transactions and scientific works in this country, and this it will be enabled to accomplish by means of its exchanges, which will furnish it with all the current journals and publications of societies, while the separate series may be completed in due time as opportunity and means may offer. The Institution has already more complete sets of Transactions of learned societies than are to be found in the oldest libraries in the United States, and on this point we speak on the authority of one of the first bibliographers of the day. This plan is in strict accordance with the general policy of the Institution, viz: to spend its funds on objects which cannot as well be accomplished by other means, and has commended itself to those who are well able to appreciate its merits, and who are acquainted with the multiplicity of demands made upon the limited income of the Smithsonian fund. In a letter, after a visit to Washington, the bibliographer before alluded to remarks: "My previous opinions as to the judiciousness of the system pursued by the Smithsonian Institution, in every respect, were more than confirmed. I hope you will not change in the least. Your exchanges will give you the most important of all the modern scientific publications, and the older ones can be added as you find them necessary. The library, I think, should be confined strictly to works of science."

A thorough examination has been made of the series of journals and transactions of societies; deficiencies have been noted, and, as far as possible, supplied, and the whole placed in the hands of the binder. This was considered indispensable for their preservation and use. The separate parts are in danger of being lost or injured so long as they remain in a pamphlet form. During the past year $2,043 have been expended in the binding of 3,668 volumes. The entire west wing of the building has been appropriated to the library, and three sides of this large apartment are now occupied with books. By placing two rows of cases, each of a double story, along the middle of the room, the amount of shelf room may be tripled, and space may thus be obtained sufficient for the wants of the library for a number of years.

It has before been observed that the Smithsonian library is intended to be a special one, as complete as possible in Transactions and all works of science. There is now in the city of Washington the large miscellaneous library of Congress and a city library of ten thousand volumes. Besides these, are the libraries of Georgetown College and of the several executive departments, and the invaluable collection of works pertaining to America, belonging to Peter Force, esq. The latter, with commendable liberality on the part of its enlightened owner, is open to the use of all who are engaged in research with reference to the speciality to which it pertains; and we trust that means will be provided by the general government to secure this collection in case of its ever being exposed to the danger of dispersion. Washington is, therefore, better supplied with miscellaneous books than any other city of the same size in the Union, and it can scarcely be considered necessary, or even just, to expend any portion of the income of the small fund intended for the good of mankind generally, in duplicating collections already to be found in the same city. Indeed it would be well if in every city of this country arrangements could be made by which each library should aim to be as complete as possible in certain branches; and we are pleased to learn that this policy has been adopted in the formation of the Astor library, the superintendent of which, in purchasing the rare books which it contains, having given a preference to such as were not to be found in any other collection in the city of New York.

To assist in rendering available the several libraries of the country, it has from the first been an object of the Institution to collect a complete set of their catalogues, and it is believed it now possesses a more extensive collection of this kind than is to be found elsewhere. Any person desiring to ascertain where a book may be obtained, can in most cases acquire the knowledge desired by addressing the Secretary of the Smithsonian Institution. At the last session of Congress an act was passed authorizing the transmission free of postage of articles entered for copyright. The effect of this law has been to diminish considerably the expense to which the Institution had been subjected in receiving books of this kind. Still there is a class of books on which postage is charged, namely, all those we receive in exchange through the mail for our own publications, including the laws and legislative documents of the several States. On the whole, the law relative to the deposite of works intended for copyright has thus far been of no real benefit; for the expense of clerk-hire, certificates, and shelf-room, would far exceed the value of all the books received in this way. While-school books, works intended for children, and the lighter and more worthless publications of the day, are forwarded to us, the larger and more valuable productions of the American press are often withheld. The principal office of these books has been to swell the number of volumes contained in the library, and in some respects to satisfy those who desire a large number of books rather than a choice collection. The process of cataloguing the library of Congress, in accordance with the plan proposed by this Institution, has been carried on under the direction of Professor Jillson, of Columbian College. The number of titles prepared is 15,885, with

7,949 cross-references—the whole number of volumes catalogued being 32,986. This number, according to Professor Jillson's report, embraces all the volumes which were in the library at the time the catalogue was commenced, with the exception of the law department, the bound volumes of tracts, and some incomplete works. It also includes the additions made in the general library to chapters 1st, 2d, 3d, and 4th, previous to April, 1855, the additions to the different chapters previous to the time they were catalogued, and at least one-half of the additions made during the past year. The whole amount expended on the preparation of the 15,885 titles is $4,971 07, and that of stereotyping about 4,000 titles, $2,974 91. This is exclusive of the expense incurred by the Institution in making the experiments on the stereotyping process, and the cost of the press, type, general apparatus, fixtures, &c.

The appropriation made by Congress has been exhausted, excepting $54 02.

Museum.—The specimens of natural history which have been received during the past year have been very numerous and of great value, the number of distinct contributors amounting to 130. As in former years, the most valuable additions have been received from the officers engaged in the various scientific expeditions of the government. An illustration of the extent of our receipts during the year is exhibited in the fact, that the specimens of mammals alone amount to 2,500.

The following is a general summary of the present state of the collections: The number of jars containing specimens of mammals in alcohol is 350: of birds, 39; of reptiles, 3,344; of fishes, 4,000; of invertebrates, 1,158; of miscellaneous, 28; making a total of 9,171 jars. Most of these contain a number of specimens; and there are about 30 barrels and cans filled with other specimens, which have not yet been assorted. There are also 1,200 prepared mammals, 4,425 birds, and 2,050 skulls and skeletons generally.

It is no part of the plan of the Institution to form a museum merely to attract the attention and gratify the curiosity of the casual visitor to the Smithsonian building, but it is the design to form complete collections in certain branches, which may serve to facilitate the study and increase the knowledge of natural history and geology.

Though the statement may excite surprise, yet I may assert, on the authority of Professor Baird, corroborated by the opinion of others well qualified to judge, that no collection of animals in the United States, nor, indeed, in the world, can even now pretend to rival the richness of the museum of the Smithsonian Institution in specimens which tend to illustrate the natural history of the continent of North America.

Not only have representatives of animals of every part of the country been obtained, to illustrate the entire American fauna, but also specimens of the same animal, from different parts, have been procured, in order to determine the geographical distribution of a species.

Of the vertebrate animals, there is scarcely a known species not already in the collection, while of those which have not yet been critically studied, there are probably a large number which have never been scientifically described.

These specimens have not, up to this time, been exhibited to the public, for want of suitable cases, in the large room, to properly display them; but they are accessible to those who are pursuing original investigations, during nearly the whole year. They have almost constantly been used for this purpose, by a succession of individuals engaged in the preparation of reports for the government, or the study of particular branches of natural history.

It is a part of the plan to give encouragement and assistance to original investigations, and persons who visit Washington for the purpose of studying the collection are furnished with all the facilities which the Institution can afford, and these, in the specimens, instruments, and the ample library of reference, are already such with regard to certain branches as cannot elsewhere be obtained.

The use of the specimens is not confined to persons who visit Washington, but, in accordance with the general policy of the Institution, they are sent to individuals who are engaged in the study of particular classes of animals, and with this view a large number of duplicates are in almost every case obtained. A considerable portion of the materials of the great work now in preparation by Agassiz will be derived from this Institution, and it is considered an important part of the duty of the directors to induce persons to undertake the study of special branches of natural history, and to afford them the means of its successful prosecution. For example, one of the researches of Dr. Leidy has been thus undertaken; and Dr. Jeffries Wyman, of Cambridge, is now engaged in the study of the peculiar character of the batrachian animals, and of the anatomical structure of the undeveloped organ of sight of the blind fish of the mammoth cave, and he has been supplied, for this purpose, with a large number of specimens of each of these animals by the Institution. In most cases of this kind the results of these investigations are published in the Smithsonian Contributions; though this is not strictly required, it being considered sufficient that full credit be given for all that has been contributed at the expense of the Institution.

The labor necessarily expended in unpacking, assorting, and labelling the specimens has been very great; and when to this is added the constant care required for the preservation of so many objects of a perishable character, the cost of the maintenance of an extended museum must be evident.

A large number of the specimens now in the museum have been procured by the several expeditions under the general government; and as in but few cases an appropriation has been made for their preservation, the expense of this has fallen on the Institution.

For a detailed account of the present condition of the collections, and the operations in the museum during the past year, I must refer to Professor Baird's report, herewith transmitted. Besides the researches mentioned, a number of explorations in natural history have been undertaken. The most important of these is that of California, by Mr. E. Samuels, under the patronage of this Institution and the Boston Society of Natural History. He expects to remain on the

Pacific coast about a year, and will doubtless secure numerous specimens in all departments of natural history, and will devote himself to completing such collections as are imperfectly represented by the results of the various Pacific railway surveys. Mr. Samuels is also charged, on the part of the Commissioner of Patents, with collecting specimens of seeds of the trees, shrubs, and grains of the country. A division of the expense, and the liberality of the Panama line, have enabled this exploration to be instituted at a small cost to each of the parties interested.

A small appropriation has also been made to assist in forming a complete collection of specimens to illustrate the zoology of Illinois, under the direction of Mr. R. Kennicott.

Another exploration was made in the northern part of the State of New York, during the past season, by Professor Baird.

The collections which have resulted from these expeditions, together with those from the Mexican boundary commission, and the several railway surveys, will furnish important additions to the natural history of the North American continent.

Lectures.—The interest in the lectures still continues, and the large lecture-room during the past winter has frequently been filled to overflowing by an attentive and intelligent audience. The plan has been adopted to give courses of lectures on special subjects, interspersed occasionally with single lectures, principally of a literary character. Courses of lectures on a single subject, it is believed, serve to convey more valuable and permanent instruction than a number of separate lectures on different subjects. To impress a general truth upon the mind, requires frequent repetition and a variety of illustrations, and hence but little impression can be made with reference to any subject involving scientific principles by a single discourse; and the lecturer who appears but once, too often attempts to interest his audience by the enunciation of vague generalizations or by mere rhetorical display.

This is, however, not always the case, since, for example, a single lecture may be given on the history of a discovery, or a brief analysis of the life of a distinguished individual.

As a general rule, therefore, we consider a number of single lectures by different persons, as of less value than a series on one subject by the same person. The latter requires a more profound acquaintance with the subject, and a greater amount of previous preparation. There are many persons who might be able to give a single popular lecture on some branch of knowledge, who would fail in attempting an extended course.

The following is a list of the lectures which were delivered during the winters of 1854–'55 and 1855–'56.*

1854–'55.—One lecture by Prof. Elias Loomis, of New York: "The zone of small planets between Mars and Jupiter."

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* In order to complete the list for the winter of 1855–'56, the lectures delivered after the date of the report have been added.

One lecture by Dr. D. BRAINARD, of Chicago, Illinois, "On the nature and cure of the bite of serpents, and the wounds of poisoned arrows."

Four lectures by Hon. GEO. P. MARSH:

1st. "Constantinople and the Bosphorus."

2d. Do. do. do.

3d. "The Camel."

4th. "Environs of Constantinople.—Political and military importance of the position of that Capital.—The reform system in Turkey."

One lecture by Dr. ROBT. BAIRD: "History of the war between Russia and Turkey, with notices of those countries."

Nine lectures by Prof. ASA GRAY, of Cambridge, Massachusetts, "On Vegetation:"

1. "Development from the seed and from buds, root, stem, and leaves.
2. Aerial, ephiphytic, and parasitic vegetation.
3. Morphology of branches.—Subterranean vegetation.—Adaptation of bulb-bearing plants and the like to regions subject to a season of drought; of forests and the like to regions of equable distribution of rain.—Anatomy and action of leaves.
4. How plants grow.—Anatomical structure.—Development from the cell.—Gradation from plants of one cell to the completed type of vegetation.
5. Wood.—The tree.—Life and duration of plants.—The individual in its various senses.—The tree a community as well as an individual.
6. How plants multiply in numbers.—The flower.
7. Fruit and seed.—Fertilization and the formation of the embryo.—Reproduction in flowerless plants.
8. Movements and directions assumed by plants generally.—The relations of vegetation to the sun.
9. Relations of vegetation to the sun continued.—The plant considered as the producer of food and a medium of force."

One lecture by Rev. J. S. FLETCHER, on "Brazil."

Two lectures by Hon. HENRY BARNARD, of Connecticut: "Recent educational movements in Great Britain."

Two lectures by Rev. E. A. WASHBURNE:

1. "Confucius, or the Chinese mind."
2. "The Chinese war."

Two lectures by Prof. JOSEPH LOVERING, of Cambridge, Massachusetts: "The progress of electricity."

One lecture by OLIVER P. BALDWIN, esq., of Richmond, Va.: "National characteristics."

One lecture by Dr. W. F. CHANNING, of Boston: "The American fire alarm telegraph."

Three lectures by ROBERT RUSSELL, esq., of Scotland, on "Meteorology."

1855-'56.—Three lectures by Prof. E. S. SNELL, of Amherst College, Massachusetts, on "Architecture;" and one lecture on "Planetary motion and disturbances."

Six lectures by Prof. O. M. MITCHELL, of Cincinnati, Ohio, on "Astronomy."

One lecture by JOHN C. DEVEREUX, esq., of New York, on "The popular influences of architecture."

Six lectures by Prof. GEORGE J. CHACE, of Brown University, Providence, Rhode Island, on "Chemistry applied to the arts."

One lecture by Prof. C. C. FELTON, of Cambridge, Massachusetts, on "Greece."

Five lectures by Rev. JOHN LORD, of Connecticut, on the "Grandeur and fall of the French Bourbon monarchy."

From the foregoing statements, I trust it will be evident that the Institution is realizing the reasonable expectations of its friends; that its funds are in a prosperous condition, and that, so long as the present policy is maintained, it will continue to promote the advance of knowledge, and thus carry out the cherished object of its founder.

Respectfully submitted:

JOSEPH HENRY, *Secretary.*

JANUARY, 1856.

APPENDIX TO THE REPORT OF THE SECRETARY.

DECEMBER 31, 1855.

SIR: I beg leave to present herewith a report for the year 1855, of operations in such departments of the Smithsonian Institution as have been intrusted by you to my care.

Respectfully submitted:

SPENCER F. BAIRD,
Assistant Secretary Smithsonian Institution.

JOSEPH HENRY, LL. D.,
Secretary Smithsonian Institution.

I.—PUBLICATIONS.

The seventh volume of Smithsonian Contributions to Knowledge was issued in July last and promptly distributed.

The octavo publications during the year have been confined to the ninth annual report, of 464 pages.

The eighth volume of Smithsonian Contributions is in an active state of forwardness, and will soon be ready for delivery.

II.—EXCHANGES.

a—Foreign Exchanges.

Owing to unavoidable delay in printing the seventh volume, the packages for foreign distribution could not be made up until the middle of July. By the end of the month, however, they were all sent off, and by October had safely reached the hands of the agents of distribution. As in past years, most of the active scientific and literary institutions of America embraced the opportunity to transmit their exchanges.

The returns during 1855 have been very valuable, considerably exceeding those of any previous year, excepting so far as relates to maps and charts. Even here, however, the decrease is more apparent than real, as several extensive series have been received, bound into volumes instead of being in loose sheets, as is frequently the case. The particulars of these returns are presented in the following tables:

A.

Table exhibiting the number of pieces received in exchange during 1855.

Volumes—folio	87	
" quarto	233	
" octavo	717	
		1,037

Parts of volumes and pamphlets—folio...	41	
" " " " quarto.	239	
" " " " octavo.	1,427	
		1,707
Maps and engravings..................................		26
Total		2,770

☞ By comparison with the table of last year, it will be seen that there has been an increase in the receipts, by 111 volumes and 239 parts of volumes and pamphlets.

The number of donations for 1855 amounts to 1,779; that for 1854 to 806.

The list of receipts for other parties during the year exhibits a large increase over that of 1854, both in the number of packages and of addresses. Thus—

In 1855 were received	1,445	packages to	44 addresses.
In 1854 were received	987	packages to	36 addresses.
Difference	458		8

The Institution is indebted for aid in expediting its parcels to Mr. Zimmerman, consul-general of the Netherlands; to Dr. Henry Wheatland, of Salem; to Lieutenant J. M. Gilliss, U. S. Navy; to the American Board of Commissioners for Foreign Missions, and to the Board of Missions of the Presbyterian church.

The following tables exhibit the chief statistics respecting the foreign exchanges for the year. To table B should be added two boxes of books sent in December to Chile, and one to London, consisting chiefly of copies of the report on Chile, made by Lieutenant Gilliss.

B.

Table showing the amount of printed matter sent abroad by the Smithsonian Institution in July, 1855.

	Addresses of principal packages.	Addresses of sub-packages enclosed.	Total of distinct addresses.	No. of principal packages to principal addresses.	No. of sub-packages enclosed to sub-addresses.	Total of distinct packages to different addresses.	No. of pieces enclosed in principal packages.*	No. of pieces enclosed in sub-packages.*	Estimated addition, where several works enclosed in one piece.	Total of volumes and pieces.	Number of boxes.	Capacity, in cubic feet.	Weight.
Distributed by Dr. Felix Flügel, Leipsic.													
Sweden	9	9	....	17	50	......	114	69	50	......	....	....	......
Norway	4	13	....	8	15	......	43	91	15	......	....	....	......
Denmark	7	12	....	14	33	......	82	110	33	......	....	....	......
Russia	20	15	....	48	104	......	250	115	104	......	....	....	......
Holland	14	12	...	27	81	......	174	77	81	......	....	....	......
Germany	123	152	....	301	485	......	1,283	945	485	......	....	....	......
Switzerland	17	19	....	31	70	......	176	106	70	......	....	....	......
Belgium	9	6	....	18	63	......	129	39	63	......	....	....	......
Total	203	238	441	464	901	1,365	2,251	1,562	901	4,714	18	188	5,361
Distributed by Hector Bossange, Paris.													
France	60	35	....	71	45	......	862	120	45	......	....	....	......
Italy	27	23	....	41	28	......	340	40	28	......	....	....	......
Total	87	58	145	112	73	185	1,202	160	73	1,435	6	76	2,185
Distributed by the Royal Society and Henry Stevens, London.													
Spain	3	3	....	6	3	......	48	7	......	......	....	....	......
Portugal	2	....	....	3	......	......	20	......	......	......	....	....	......
Great Britain and Ireland	95	148	....	200	490	......	1,022	701	......	......	....	....	......
Total	100	151	251	209	493	702	1,090	708	442	2,240	5	74	2,285
Distributed in other parts of the world	28	10	38	40	10	50	196	10	......	206	4	20	650
Grand total	418	457	875	825	1,477	2,302	4,739	2,430	1,416	8,585	33	358	10,481

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* Addressed packages from other institutions count only as one each, although containing sometimes as many as a dozen pieces.

C.

Table of packages received in 1855 *from American institutions for distribution abroad.*

Boston—	
American Academy of Arts and Sciences	146
Natural History Society	49
Cambridge—	
Observatory Harvard College	124
Botanic Garden	16
New Haven—	
American Journal Science	40
Albany—	
New York State Library	5
New York State Agricultural Society	1
New York—	
American Geographical and Statistical Society	150
Philadelphia—	
American Philosophical Society	28
Philadelphia Academy of Natural Sciences	91
Philadelphia College of Pharmacy	1
Pennsylvania Institute for Blind	48
Historical Society of Pennsylvania	1
Washington—	
Secretary of War	6
United States Patent Office	200
Bureau of Ordnance and Hydrography	78
United States Naval Astronomical Expedition	20
Columbus, Ohio—	
Ohio State Board of Agriculture	126
Detroit—	
Michigan State Agricultural Society	47
New Orleans—	
New Orleans Academy of Natural Sciences	200
San Francisco—	
California Academy of Natural Sciences	46
Geological Survey of California	128
Santiago, Chile—	
University of Chile	147
Observatory of Santiago	34
Various individuals	980
Total	2,712

D.

Table of packages received from Europe for distribution to various societies in America.

Canada—	
Various institutions	7
Boston—	
American Academy of Arts and Sciences	74
Natural History Society	20
Bowditch Library	13
Cambridge—	
Observatory	26
Botanic Garden	41
Harvard University	39
Astronomical Journal	28
American Association for Advancement of Science	6
Worcester—	
American Antiquarian Society	6
New Haven—	
American Journal of Science	36
American Oriental Society	7
Providence—	
Brown University	10
Albany—	
Albany Institute	17
New York State Library	27
State Agricultural Society	1
New York—	
Lyceum of Natural History	23
American Ethnological Society	1
Geographical and Statistical Society	5
American Institute	13
Astor Library	15
West Point—	
United States Military Academy	2
Philadelphia—	
American Philosophical Society	72
Academy of Natural Sciences	45
Franklin Institute	17
Geological Survey of Pennsylvania	3
Washington—	
President of the United States	1
United States Patent Office	23
Congress Library	15
United States and Mexican Boundary Survey	1
United States Coast Survey	33
National Observatory	38
National Institute	26
Commissioner of Indian Affairs	1
United States Naval Astronomical Expedition	19

Georgetown, D. C.—	
Georgetown College	29
Cincinnati—	
Observatory	12
Columbus—	
Ohio State Agricultural Society	2
Detroit—	
Michigan State Agricultural Society	8
Ann Arbor—	
Observatory	4
Madison—	
Wisconsin State Agricultural Society	26
Colleges in different places	117
Various State Libraries	28
Miscellaneous societies and individuals	508
Total	1,445

By reference to the preceding tables, it will be seen that the Institution acts as agent not only for parties in the United States and Canada, but also for the University and Observatory of Chile.

The facilities for conducting the Smithsonian exchanges have been greatly increased by the liberal act of the mail line of steamships to California *via* Panama, in carrying, without charge, its parcels for the west coast of America. The line of steamers to Bremen has also granted the same privilege. Messrs. Oelrichs & Lurman, of Baltimore, as in previous years, have marked their sense of the value of the operations of the Institution by making no charge whatever for their agency in shipping from Baltimore the large number of boxes sent to Bremen, and in receiving and forwarding others from that port.

b—Domestic Exchanges.

The copies of volume VII of Smithsonian Contributions were distributed promptly through the following agents, whose services, as heretofore, have been given without charge: Dr. T. M. Brewer, Boston; George T. Putnam & Co., New York; J. B. Lippincott & Co., Philadelphia; John Russell, Charleston; B. M. Norman, New Orleans; Dr. George Engelmann, St. Louis; H. W. Derby, Cincinnati; and Jewett, Proctor & Worthington, Cleveland.

Nearly all the parties to whom copies were addressed have already returned acknowledgments to the Institution.

A few copies of volumes IV and V of the History, Condition, and Prospects of the Indian Tribes of the United States have been distributed in behalf of the Commissioner of Indian Affairs.

III.—MUSEUM.

A—*Increase of the Museum.*

The year 1854 was a marked one in the history of the Institution, on account of the magnitude and intrinsic value of the collections received. These were mainly from the survey for marking the boundary between the United States and Mexico, and those for a practical railroad route to the Pacific, from the North Pacific exploring expedition under Captain Ringgold, and the expedition to the Parana and its tributaries under Captain Page, from the exploration of the coast of California by Lieutenant Trowbridge, and many others, enumerated in detail in the last report. It was supposed that, with the return of most of these expeditions, and the diminution in extent of the field of labor, the receipts during the year 1855 would show a considerable falling off. This, however, has by no means been the case; on the contrary, the additions have not only been greater in number, but of even greater interest, many new regions having been almost exhausted of their scientific novelties. The following table will illustrate the difference in the receipts for the two years:

	1854.	1855.
Number of kegs and barrels received	35	26
Do. cans	26	18
Do. jars	175	187
Do. boxes	94	148
Do. bales	—	7
Do. packages	32	79
Do. cabinets	—	2
Total of pieces	362	467
Distinct donations	130	229

The entire number of different contributors during 1855 has exceeded 130. There has been a considerable decrease in 1855 in the number of fishes and reptiles received, owing to the fact that full collections have been made in previous years at many points, which thus became exhausted as far as contributions of desirable specimens were concerned. In the department of mammals, however, the increase over previous years has been very marked, in consequence of a circular which you issued early in the year calling attention to the subject. The number of specimens received, preserved either in alcohol or as dry skins, amounted nearly to 2,500, an aggregate which few museums in the world can probably give, as received in the same space of time.

As in 1854, the most important of the collections received, whether their extent or novelty be considered, were made and sent home by the government exploring expeditions, as follows:

a—THE MEXICAN BOUNDARY LINE.

Survey of the boundary between the United States and Mexico—Major W. H. Emory, U. S. A., commissioner.—In the last annual report, attention was called to the fact that the active survey of this line had been resumed, for the purpose of accurately marking the new portion of the United States boundary, acquired by the Gadsden treaty. The party of the Commissioner left Washington in September for the field of operation, and got back to San Antonio in one year, after running a boundary line of seven hundred miles in length. Operations were commenced simultaneously at both extremities of the line, Major Emory himself taking charge of the eastern end, and intrusting the western to Lieutenant Michler.

As in all previous surveys of the Mexican boundary line, much attention was paid to the collection of facts and specimens illustrating the Natural History of the region traversed, and very full series of the animals, plants, minerals, and fossils, were secured by the gentlemen specially charged with this duty—namely, Dr. C. B. Kennerly, surgeon of the expedition; Captain E. K. Smith, commander of the escort; and Arthur Schott, esq., assistant to Lieutenant Michler.

The collections thus made, at the close of the field labors of the Boundary Survey, were in no respect inferior to the preceding ones, and formed an appropriate winding up of the natural-history operations of a great work. The pioneer of all those government explorations which have yielded such important fruits to natural science, traversing hundreds of miles previously unvisited by the naturalist, and provided with a scientific outfit devised expressly for it, and well-tested previously to its adoption by other parties, the Mexican Boundary Survey has imperishably identified itself with the history of the progress of science in the collecting of perhaps a larger number of new species of North American animals and plants than any one party ever gathered before, or will again.

b.—REGIONS WEST OF THE MISSOURI.

Exploration of northern route for Pacific railroad, under Governor I. I. Stevens.—The rich results of explorations along this line have already been adverted to. The naturalists of the expedition—Dr. George Suckley and Dr. J. G. Cooper—after the expiration of their connection with the survey in 1854, continued making collections of facts and specimens at their own expense, and added much to their previous acquisitions. The numerous specimens gathered by Dr. Cooper, principally at Shoalwater bay and near San Francisco, have not yet been all received: those of Dr. Suckley, made at the Dalles, Fort Steilacoom, and in various portions of Oregon, have arrived, and are of the first importance. They are especially rich in mammalia, and will again be referred to.

Exploration of California by Lieut. Williamson.—Lieut. Williamson, after completing the report of his survey of 1853, was sent out again in May last to examine the region along the Cascade range of mountains in California and Oregon, for the purpose of discovering, if possible, a practicable pass through these rugged mountains. His labors were completed in November, and in December Dr. J. S. Newberry, geologist and naturalist of the party, arrived in Washington with the rich fruits of his labors, consisting of full collections in all departments of natural history. In mammals this collection is especially ample, containing among others many of the larger species, as bears, deer, &c., not previously secured by any expedition. Facts of the greatest interest in the geographical distribution of many forms were obtained, especially in determining the existence west of the Cascade mountains of the genera *Coregonus*, *Siredon* and *Scaphiopus*.

Dr. Newberry brought with him a donation to the Institution by Dr. W. O. Ayres, of San Francisco, of a series of types of his new species of California fishes, which will prove of very great value for comparison.

The exploration under Lieut. J. G. Parke in California has also returned to Washington with important collections, mainly in geology and botany, made by Dr. Antisell. The expedition under Capt. Pope, for the purpose of testing the question of artesian boring on the plains, is still in the field, where Capt. Pope is engaged in continuing the natural history explorations commenced by him in previous expeditions. No specimens have, however, been received from him during the year.

Survey in Texas of Capt. R. B. Marcy.—The collections made by Dr. Shumard during this survey, referred to in 1854, were not received until the present year, having been detained for many months at Fort Smith by low water in the Arkansas. They consist of many interesting specimens of vertebrates, insects, and plants, with full series of the minerals and fossils of that region.

Collections made by Dr. Anderson, U. S. A., at Fort McKavit, Texas, have served to illustrate still further the zoölogy of this State.

Lieut. W. P. Trowbridge.—The researches of Lieut. W. P. Trowbridge, U. S. Engineers, superintendent on the Pacific coast of the tidal stations of the U. S. Coast Survey, have been vigorously continued since last year, as shown by the record of his donations, consisting of many specimens of vertebrates and invertebrates from different points, as Cape Flattery, Astoria, San Francisco, the Farallones, and San Diego. No one explorer, unaided by government resources, has done so much in the way of collections in American zoölogy as Lieut. Trowbridge accomplished by his own personal labor, assisted by Messrs. James Wayne, T. A. Szabo, and Andrew Cassidy, tidal observers under his command. It is thus that the operations of the Coast Survey, under the liberal countenance of its chief, have tended to advance the knowledge of the natural history of our coast to a degree only second to that of its physical features.

To Richard D. Cutts, esq., in charge of a surveying party of the Coast Survey, the Institution is indebted for specimens of the mammals, birds, reptiles, and fishes of California, of rare excellence of preservation and scientific interest.

Another exploration made by a party of the U. S. Coast Survey was conducted by Mr. Gustavus Würdemann, in continuation of former efforts of similar character on the coasts of Louisiana and Texas. Mr. Würdemann's operations were carried on at Indian river, Florida, on the St. John, and on the coasts of Georgia and South Carolina, at which places he gathered many interesting specimens of animals.

Dr. J. F. Hammond, U. S. A., stationed at Fort Reading, sent in some valuable collections from that part of California. Specimens from Fort Yuma were presented by Major G. S. Thomas, Lieut. Patterson, and Dr. R. P. Abbott, of the U. S. army.

Geological Survey of Oregon.—A large number of boxes of minerals and fossils have been received from Dr. J. Evans, now occupied in the geological survey of Oregon. To these were added a number of specimens of the mammals and birds of Oregon, as well as some still more valuable from the region of the Upper Missouri.

Explorations on the Missouri.—The explorations on the Upper Missouri and Yellowstone, by Dr. F. V. Hayden, in connexion with Col. Vaughan, Indian agent, Mr. Alex. Culbertson, and Mr. Chouteau, continue to yield results of much importance. Large collections of fossils, minerals, mammals, birds, insects, and plants, have been made and sent in.

Dr. Hayden has revisited the Mauvaises Terres of White river during the year, and procured some forms of fossil mammals not previously discovered. The Mauvaises Terres of the Blackfeet country have also furnished him a rich harvest. His geological collections now amount to nearly six tons in weight.

The expedition of United States troops under Gen. Harney against the Sioux has also resulted in the collecting of many specimens of fossil mammals and reptiles in the Mauvaises Terres. Most of these will probably go to enrich the cabinet of the U. S. Military Academy at West Point.

A valuable series of specimens, made at Fort Benton, on the Upper Missouri, by Mr. Harvey, was received during the summer, and serves to complete the collections in the same vicinity by Dr. Geo. Suckley.

Exploration of Mr. Samuels.—The exploration of California by Mr. E. Samuels, under the patronage of the Smithsonian Institution, the Boston Society of Natural History, and the United States mail line to California—consisting of the United States Mail Steamship Company, (M. O. Roberts, esq., president,) the Panama Railroad Company, (David Headly, president,) and the Pacific Steamship Company, (Mr. Aspinwall, president)—promises to do much towards the development of the natural history of that State. Mr. Samuels left New York on the 5th of November, and by last advices had arrived in San Francisco. He expects to remain in California about a year, and will secure numerous specimens in all departments of natural history, devoting particular attention to completing such collections as are imperfectly represented in the results of the various Pacific railroad surveys. The above-mentioned companies have, in the most liberal spirit, granted free passage to Mr. Samuels and his collections, besides adding other facilities, thereby reducing materially the expenses of the work.

The California Express Company of Messrs. Wells, Fargo, & Co., and J. M. Freeman & Co., at the suggestion of officers of the Panama line, have instructed their agents in California to render Mr. Samuels all the aid in their power.

In addition to his other collections, Mr. Samuels is specially charged by the Commissioner of Patents with securing seeds of the trees and shrubs of California for distribution throughout the country.

c—REGIONS EAST OF THE MISSOURI.

In anticipation of the great fair in Chicago of the Illinois State Agricultural Society, it was proposed to secure and exhibit full collections of the natural history of the State on that occasion. Accordingly, Mr. Robert Kennicott was selected by the society to travel throughout Illinois, especially along the lines of the Illinois Central railroad, and not only to make collections himself, but to instruct the employés of the railroad company and others, so as to enable them to assist in the work. Aided by a small appropriation by the Institution, in addition to the facilities furnished by the society and the railroad company, Mr. Kennicott collected in a few months the finest cabinet of Illinois specimens ever brought together. This collection constituted one of the most striking features of the fair, and after the latter was closed was in great part forwarded to the Smithsonian Institution. It is much to be regretted that a very large and valuable collection of living reptiles of Illinois, transmitted by Mr. Kennicott, should have been destroyed through a misunderstanding with the express company. To Mr. Kennicott is due the praise of having been the first to enter on a systematic zoölogical exploration of Illinois. Thanks to his efforts, we have few States better, or even so well, represented in our cabinet. In this labor he has been worthily seconded in the more southern portions of the State by Mr. William J. Shaw,* from whom many valuable collections, especially of insects, have already been received.

In company with William A. Henry, esq., I visited the wild regions of northern New York, for the purpose of studying the habits, and collecting specimens, of the mammals inhabiting it. With the assistance of Mr. M. Baker, of Saranac Lake, we succeeded very well in accomplishing our object.

Mr. Henry and myself also visited the region along the St. Lawrence, and made some interesting collections, aided by Mr. E. A. Dayton, of Madrid, and Mr. W. E. Guest, of Ogdensburg.

d—MEXICO.

Two very important additions to our collection of specimens, illustrating the natural history of Mexico, have been received during the year. The first consists of a series of types of Mexican serpents as described in the Erpetologie generale of Messrs. Duméril and Bitoron, and presented by the Jardin des Plantes, of Paris, through the agency of the Messrs. Duméril. The other collection was forwarded by John Potts, esq., and contains specimens of reptiles, fishes, birds, and mammals, made in central and northern Mexico, and all in the highest state of preservation. Some of the specimens were received by Mr. Potts for the Institution from Mr. Schleiden. Additional collections from Mexico are earnestly desired, as serving to determine more accurately the nature and geographical distribution of North American

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* Since writing the above, intelligence has been received of the death of Mr. Shaw.

animals. Thanks to the disinterested zeal of Mr. D. N. Couch, formerly of the United States army, we already possess, in the rich collections made by himself and Dr. Berlandier, very full series from many provinces of northern Mexico, as Tamaulipas, Coahuila, New Leon, Durango, &c. The fruits of the travels of Dr. Thos. Webb, in the more western portions of northern Mexico, are also of very great value. The vicinity of the city of Mexico is probably the point where the Mexican specimens of most interest are to be derived.

e—SOUTH AMERICA AND THE REST OF THE WORLD.

Survey of North Pacific and China seas, under Commander John Rodgers, United States Navy.—The collections made by this naval exploring expedition, while first in charge of Captain Ringgold, and subsequently of Captain Rodgers during 1854 and part of 1855, have been received in good order, and consist of many boxes and kegs of specimens in zoölogy and botany, collected chiefly by Messrs. Wm. Stimpson and Charles Wright, naturalists to the survey. These specimens are principally from the South Pacific and the China seas. Collections of very great interest were made during the past spring and summer about Japan, Kamschatka, and in and along Behring's straits, and subsequently on the coast of California.

The Japan Expedition, under Commodore Perry, was also the means of adding some fine collections of birds, reptiles, and shells to the zoölogical treasures of the country.

From Dr. James Morrow, agriculturist to the expedition, has been received a number of jars filled with reptiles and fishes of Japan, embracing several novelties in science.

Exploration of the Parana, under Captain T. J. Page, United States Navy.—This expedition has continued its important agency in developing the natural history resources of Paraguay, by sending home many specimens of the mammals, birds, reptiles, fishes, invertebrates, plants, minerals, &c. These, with previous collections from the same source, constitute the most important series of South American animals, especially of the reptiles and fishes, ever brought to the United States.

Arctic Expedition of Dr. Kane, United States Navy.—During the recent voyage of Dr. Kane along the west coast of Greenland, many collections in natural history were obtained. It became unfortunately necessary to abandon them, however, after the vessel became frozen up, and the party was obliged to return in sledges.

f—GENERAL STATEMENTS OF ADDITIONS.

I shall now proceed to discuss briefly the more important contributions to the museum during the past year, referring for particulars to the general list of donations.

Mammals.—The most marked increase during the year has been in the collection of mammals, of which about 2,500 specimens were received. Much the larger number of these, as might be expected, consisted of very small species, as of ***Arvicola***, *Sorex*, *Hesperomys*, &c., although many of the larger kinds, as bears, deer, wolves, foxes, &c., are included. Most of the specimens were preserved entire in alcohol, affording means of anatomical as well as zoölogical research. About eight hundred skins have been registered as received or prepared in the Institution. The additions to this department have been from all parts of the world, including an interesting collection of English species from Sir W. Jardine.

One of the most important contributions to the geographical collections of the institution has been the series of mammals of eastern Massachusetts, received from Mr. J. W. P. Jenks, of Middleboro. Large numbers of all the species from about Middleboro have been collected and forwarded by Mr. Jenks, amounting to over eight hundred specimens, and with the result of adding several species to those known to inhabit the State.

Another collection of mammals of nearly equal extent, but of less variety of species, was made in Clarke county, Virginia, at the instance of Dr. Kennerly, by Mr. John A. Kniesley. This also contains some rare species. Others were received from Mr. Bridges, in North Carolina. The Rev. M. A. Curtis, of South Carolina, aided by his sons, has also furnished the largest number of mammals, both specimens and species, ever received from the southern States.

Birds.—Of birds, several thousand specimens have been received; the most important from the west coast of America. The principal extra limital collections were from the expeditions of Captain Ringgold, Captain Rodgers, Commodore Perry, Captain Page, and Lieut. Gilliss. Mr. Naffer presented some very rare species from the Philippine Islands; and Dr. Tolmie a series of skulls of birds of the Pacific ocean, as penguins, cormorants, &c.

Reptiles.—Many interesting collections of reptiles have been received from different portions of North America and Mexico, as well as from other parts of the world. Among the species collected in Japan by Commodore Perry is a specimen of the *Plestiodon*, supposed by authors to be identical with a North American lizard, (*P. quinquilineatus*.) The collection of types of Mexican species from the Jardin des Plantes has already been referred to.

Fishes.—The number of fishes received has been less than in previous years, although by no means deficient in interest. Those from west of the Rocky mountains were mostly made by the government expeditions, as also by Lieutenant Trowbridge, Dr. Ayres, Dr. J. F. Hammond, Dr. Cooper, Dr. Suckley, Mr. Cutts, &c. The most important of the eastern were a collection from the Tortugas, made by Lieutenant H. G. Wright, U. S. Navy, assisted by Dr. Whitehurst, and one from the Maumee river, by Mr. George Clark. Some Cuban fishes were presented by Professor F. Poey, of Havana, and some South American, by Thomas Rainey, esq., United States consul.

Invertebrates.—The principal addition to the series of invertebrata, not yet mentioned, consists of two large cabinets, containing the valuable and extensive collection of shells belonging to General Totten, and deposited by him. Such a collection has been much needed in the Institution for purposes of comparison.

Plants.—A series of the plants of the Berlandier collection, selected by Dr. Gray, was presented by Dr. Short, of Louisville. By special request of Lieutenant Couch, Mr. Ervendberg forwarded a collection from Comal county, Texas, and Dr. Glisan one from Fort Arbuckle. Seeds of a valuable Texan grass were received from Major Carleton.

Fossils and Minerals.—The very valuable collection of minerals and fossils collected in the Lake Superior mining region by Messrs. Foster and Whitney, and illustrating their government report, has been received during the year, and with the other government geological collections, previously secured, furnish rich material for representing the geological features of the country. The Oregon collections of Dr. Evans have been already mentioned.

A collection of Niagara fossils and minerals was received from Thomas Barnett, esq.

Miscellaneous.—A fine specimen of the Australian Boomerang, and other articles, were received from Mr. Carrington Raymond, of New York. From Mr. N. Trübner were obtained two sets of microscopic slides: one containing illustrations of organic tissues and organs; the other constituting a complete system of entomology, in numerous mounted preparations, showing the family characteristics of the principal orders of insects.

Living Animals.—Among the additions to the museum during the past year have been quite a number of living animals, some of them species of great rarity, or else but seldom seen out of their native localities.

These have answered an excellent purpose in serving as models for drawings by the various artists engaged in figuring the collections of the different surveying and exploring expeditions.

Although the institution is, of itself, unable to provide suitable accommodations for the larger mammals and birds, it is fortunate in the zealous co-operation of Dr. Nichols, the superintendent of the United States Insane Asylum, who cheerfully receives any specimens sent him, and gives them every attention which they may require. As a source of harmless amusement and mental diversion to the patients of an insane asylum, a collection of living animals has no equal, and it is much to be desired that the number at the Washington asylum may be materially increased.

The most conspicuous addition to the menagerie of the institution is a huge grizzly bear, (*Ursus ferox,*) received in July. It was caught in 1853, while quite young, by Dr. John Evans, United States geologist, during his overland journey to Oregon, and sent to Mr. Hendricks, in Indiana, by whom, after two years' time, it was forwarded to Washington. It is now a little more than two and a half years' old, and has already attained a large size, weighing probably five or six hundred pounds.

Dr. Evans has also forwarded, through D. D. Owen, two living wild cats, (*Lynx rufus*,) from the Upper Missouri. One of these died last spring ; the other still survives.

A fine specimen of the American antelope (*Antelope americana*) was presented by Dr. W. W. Anderson, of South Carolina, and was, as far as I can learn, the first living one brought to the Atlantic States, although the species is very common on the Western plains. It was taken in the vicinity of Fort McKavit, when quite young, by Dr. W. W. Anderson, U. S. A., together with a Virginia deer, (*Cervus virginianus*,) likewise presented to the Institution. The antelope, unfortunately, died from some unknown cause, some months ago; the deer is still in good health.

Among the small quadrupeds, received alive, of most interest is a specimen of the grey gopher, (*Spermophilus franklinii*,) presented by Robert Kennicott, esq. This species is an inhabitant of the prairies of Illinois, Iowa, and Wisconsin, and probably of Minnesota, and the plains north of it. In some of its habits, it is not dissimilar to the prairie dog, (*Cynomys ludovicianus*.) Several squirrels, (*Tamias americana*, *Sciurus migratorius*, *&c.*,) together with some wild mice and moles, have also been received from various sources. A living racoon has also been received from California.

A pair of young roseate spoonbills, (*Platalea Ajaja*,) caught in Florida, was presented by Mr. Würdemann.

Very large numbers of living serpents, embracing many rare species, have been received from different regions ; much the greater number, however, from Illinois, where they were collected by Mr. Kennicott. Others were presented by Mr. Sergeant, Mr. Kirkpatrick, &c. A portion of the specimens from Illinois were sent to the Jardin des Plantes, in charge of Mr. J. H. Richard, but were wantonly thrown over-board during the passage by a young American, to the profound regret of this Institution, and of the administrators of the Paris Museum d'Histoire Naturelle. A second collection, duplicate of the first, sent by Mr. Kennicott, was destroyed by the Express Company, to whose charge it was commited in Chicago. A long time will probably elapse before some of the species can be replaced.

Some interesting species of living frogs, salamanders, &c., have also been received, together with a considerable number of turtles.

In view of the very great number and extent of donations to the museum in 1855, as well as of the limited space allotted to me, it is clearly impossible to mention here in detail any but the most important, and even some of these must be omitted. As an index, however, to the alphabetical list of donations herewith presented, I have prepared the following tables—the first, showing the principal additions by States ; in the second, the arrangement is by systematic classification :

I.—GEOGRAPHICAL INDEX TO SPECIMENS RECEIVED.

***Washington and Oregon.*—Andrews, Cooper, Evans, Tolmie, Suckley.**

California.—Abbott, Ayres, Baird, Campbell, Cooper, Cutts, Hammond, Newberry, Patterson, Taylor, Thomas, Trowbridge, Williamson.
Southern Boundary.—United States and Mexican Boundary Commission.
Texas.—Anderson, Carleton, Ervendberg.
Louisiana.—Andrews.
Arkansas and Indian Territory.—Glisan, Marcy, Shumard.
Missouri.—Engelmann, Hilgard, Shumard.
Kansas.—Couch, Hammond.
Nebraska.—Evans, Harvey, Hayden, Vaughan.
Iowa.—Moore, Stevens.
Wisconsin.—Barry, Child, Hoy, Kumlien.
Lake Superior.—Agassiz, Foster, Whitney.
Illinois.—Kennicott, Sergeant, Shaw.
Ohio.—Clark, Kirtland, Kirkpatrick, Lesquereux, Wormley.
Kentucky.—Grant.
Tennessee.—Means.
Alabama.—Pybas.
Mississippi.—Robinson, Spillman.
Florida.—Casey, Whitehurst, Wright, Würdemann.
Georgia.—Leconte, Neisler, Postell.
South Carolina.—Anderson, Barratt, Curtis, Morrow, Ravenel, Weston.
North Carolina.—Bridger, Dewey, Erwin, Fitzgerald.
Virginia.—Goldsboro, Kniesley, McDonald, Palmer, Robertson.
District of Columbia.—Brown, Dougal, Herder, Johnson, Nichols.
Maryland.—Bowers.
Pennsylvania.—Patton.
New York.—Baird, Davis, Dayton, Hall, Howell, Lawrence, Oakley, Ward, Welsh.
Connecticut.—Plumb.
Vermont.—Thompson.
Massachusetts.—Agassiz, Brewer, Jenks, Wyman.
British Provinces —Barnett, Bell, Dawson, Montreal Natural History Society, Wyman.
Cuba.—Poey.
Mexico.—Jardin des Plantes, Potts.
South America.—Gilliss, Nichols, Page, Rainey.
Europe.—Clark, Easter, Jardine, Karsten, Sturm.
China, Japan, and South Pacific Ocean.—Agassiz, Gulick, Morrow, Ringgold, Rodgers.
East Indies.—Napper.
Australia.—Raymond.

II.—SYSTEMATIC INDEX TO SPECIMENS RECEIVED.

Mammals.—Agassiz, Anderson, Ayres, Baird, Barratt, Barry, Brewer, Bridger, Brown, Campbell, Child, Clarke, Cooper, Couch, Curtis, Cutts, Davis, Dawson, Dougal, Engelmann, Evans, Hale, Hammond, Howell, Hoy, Jardine, Jenks, Kennicott, Kniesley, Kirtland, Kumlien, Lawrence, Leconte, Montreal Natural History Society, Moore, Morrow, Nichols, Shaw, Stevens, Sturm, Suckley, Thompson, Trowbridge, Vaughan & Hayden, Tuley, Welsh, Würdemann, Wyman.

Birds.—Bowers, Couch, Curtis, Cutts, Davis, Fitzgerald, Gulick, Johnson, Kennicott, Napper, Postell, Pybas, Shaw, Sturm, Suckley, Tolmie, Trowbridge, Vaughan & Hayden, Würdemann.

Reptiles.—Abbott, Andrews, Anderson, Baird, Bridger, Curtis, Cutts, Easter, Engelmann, Evans, Fitzgerald, Goldsboro, Hammond, Howell, Jardin des Plantes, Kennicott, Kirkpatrick, Kirtland, Lesquereux, Palmer, Patterson, Postell, Pybas, Sergeant, Shumard, Spillman, Suckley, Trowbridge, Vaughan & Hayden, Ward, Weston, Wormley, Würdemann, Wyman.

Fishes.—Agassiz, Anderson, Baird, Casey, Clark, Cutts, Dayton, Evans, Grant, Hammond, Howell, Kennicott, Means, Poey, Rainey, Shumard, Spillman, Suckley, Trowbridge, Vaughan & Hayden, Weston, Wormley, Wright, Würdemann, Wyman.

Invertebrates.—Barratt, Easter, Engelmann, Hammond, Lewis, Neisler, Ravenel, Shaw, Totten, Trowbridge, Wilson, Wright.

Plants.—Carleton, Eversfield, Glisan, Hilgard, Short.

Fossils and Minerals.—Andrews, Barnet, Dewey, Erwin, Foreman, Karsten, Oakley, Pybas, Ravenel, Spillman, Thomas, Vaughan & Hayden.

Miscellaneous.—Raymond, Ringgold, Trübner.

B—*Work done in the Museum.*

Owing to the very great number of specimens received weekly at the Institution, the labor involved in unpacking, assorting, and labelling, has been very onerous, considerably greater than in 1854. No arrears, however, have been suffered to accumulate, every collection on its arrival being promptly entered on the books of registry, and appropriately ticketed, with date, locality, &c. In this labor, as in previous years, I have been assisted by Dr. Charles Girard.

A considerable amount of taxidermical work has also been performed within the walls of the Institution; several hundreds of skins of mammals and birds, and an equal number of skulls, having been prepared. All such specimens as admitted of it have been regularly catalogued on the books of the museum: the serial numbering of prepared mammals having been advanced, during the year, from 351 to 1,200; of birds, from 4,354 to 4,425; of skeletons and skulls, from 1,276 to 2,050. The entries of mammals and skulls have been brought completely up; those of several collections of birds have, however, been purposely deferred for the present.

All the collections of vertebrata in the Institution (with the exception of the fishes) have, during the year, been re-arranged systematically on shelves or in drawers, so as to bring together all the specimens of each species. Owing to the want of space, this could not be done previously; the acquisition of several additional rooms has, however, supplied all the accommodations at present necessary. Nothing satisfactory can be done with the collection of fishes, now filling 4,000 jars, until the erection of cases in the main hall shall furnish a suitable place of exhibition.

During the past year my own leisure time has been chiefly employed in working up the mammalia of the collection, and the monographing of the genera has been completed, with the exception of a few families.

Particular attention has been paid to the study of the skulls and skeletons of the species, for which the large collections of the Institution affords unrivalled facilities. C. Girard has also prepared several zoölogical monographs.

C—*Present Condition of the Museum.*

The richness of the museum of the Smithsonian Institution at the present time must be a source of national pride to all who are desirous of seeing at Washington a satisfactory exposition of the natural history of North America. No collection in the United States, nor indeed in the world, can pretend to rival it in this respect. Every part of our continent, from the British line on the north to central Mexico on the south, has abundant representatives here of its peculiar inhabitants, while the collocation of specimens of one species from many different localities furnishes materials towards determinations of geographical distribution of inestimable value. Thus of the known species of North American vertebrata there is scarcely one not already in our possession, while of nondescripts we have scores. Among the mammals alone it is probable that the final result of a critical examination of the specimens will be the addition of over fifty species to the list, given recently by Messrs. Audubon and Bachman, most of them being new to science.

Of North American reptiles but two or three of those described by Holbrook are wanting, while his aggregate has been more than doubled.

The following table will illustrate the statistics of the alcoholic collections at the present time, while the addition of similar data for 1851 will show the increase in four years. Five years is the entire period during which the collections generally of the Institution have been forming; and when it is considered that no purchases whatever have been made, save of an occasional specimen in the city market, it must be admitted that few Institutions, even those under the direct patronage of wealthy governments, can present such results. Nearly every specimen, too, has been collected at the express instance of the Institution.

Table exhibiting the number of jars, with specimens in alcohol, in the Smithsonian Institution December 31, 1855, *compared with December* 31, 1851.

	1851.	1855.
Mammals	36	350
Birds	none	39
Reptiles	554	3,344
Fishes	1,082	4,000
Invertebrates	150	1,158
Miscellaneous	65	280
Total	1,887	9,171

In the above enumeration it should be borne in mind that many of the jars of invertebrata and of fishes contain a considerable number of species each, while there are at least thirty barrels, kegs, or large cans filled with specimens, which it has not yet been convenient to separate and assort.

An equally gratifying increase is shown in the skins and skeletons, of which a table similar to the preceding is herewith presented:

	1851.	1854.	1855.
Prepared mammals	none	351	1,200
Birds	3,700	4,354	4,425
Skulls and skeletons generally	912	1,276	2,050

An addition, however, of at least 1,500 specimens of North American birds is to be made to this list of specimens in hand, but not yet regularly entered.

Catalogue lists of shells, insects, minerals, fossils, plants, &c., have not yet been prepared, although the increase here has likewise been very great.

D—*Principal Desiderata of the Museum.*

Although the collections received by the Institution have been so large and valuable, there are still some special desiderata, which it may be well to mention here, in hopes of having them supplied. Among the mammals east of the Mississippi most wanted are the two species of swamp rabbit; the one (*Lepus aquaticus*) found in Mississippi, Louisiana, and Alabama, considerably larger than the common gray rabbit, (*L. sylvaticus;*) the other from the Atlantic southern States, near the seaboard, (*L. palustris,*) smaller than that last mentioned. Next to these come the squirrels, especially the rusty-bellied varieties, from the southern and western States. The various kinds, even those most common, of the mice, moles, shrews, &c., are very desirable.

A particular desideratum, as yet unsatisfied, is the Florida pouched rat, or "salamander," (*Geomys pineti*,) abundant in Florida and Georgia, where, though its heaps of earth are met with in every direction, the animal itself is rarely seen and caught. A steel trap set at night, and baited with sweet potatoes, or other vegetable substance, would probably secure them readily, as the western species may be taken in like manner.

While the species from the west of the Missouri are universally desirable, the large reddish-brown hare of northern Texas, the black and grizzly bear, the wolverine or glutton, the black-tailed deer of the Missouri, and the Rocky mountain goat, are of particular interest.

As an additional illustration of our desiderata among the mammals, I subjoin a copy of a circular on the subject, issued by you last spring, and containing special instructions for preserving and forwarding.

Skeletons, with skulls of mammals, as indeed of all vertebrata, are always desirable.

Of birds, the most prominent desiderata from the eastern portion of the continent are the American golden eagle, (*Aquila chrysaetos*,) the flamingo, (*Phœnicopterus ruber*,) and the courleco, (*Aramus scolopaceus*,) from Florida, and the trumpeter-swan, (*Cygnus buccinator*,) of the upper Mississippi.

Eggs of birds are always desirable, especially such as may serve to complete the work of Dr. Brewer on American eggs, now under way.

Among the North American reptiles, there are but two species of serpents described by Dr. Holbrook not in the collection ; these are the *Coluber couperi*, or gopher snake, a very large, thick blue-black snake, found on the dry pine hills on the seaboard of Georgia, especially along the Altamaha river ; the other is the *Trigonocephalus atrofuscus*, a copper-head snake, having subquadrate blotches on the back, and quite dark in color. This species is found in Tennessee.

Of the tortoises, any terrapins from the Atlantic, Gulf coasts, or the West, are desirable, and these can readily be sent alive. The Florida land-turtle, or "gopher," is also wanted. Of the salamanders, large numbers of the *Menobranchus*, *Menopoma*, *Siren*, and *Amphiuma*, are always wanted for dissection or distribution. These may be popularly described as lizard-shaped animals, with slimy skins, living in water or mud, especially of rice-fields, (from the southern kinds,) having two or four legs, and with or without gills on the sides of the neck. They are usually called alligators in the western States, though erroneously; in size they range from six inches to two feet.

Of fishes, those particularly desirable are the species of sunfish, &c., found in fresh-water creeks, emptying directly into salt or brackish water.

E—*Premiums for Collections.*

It may, under certain circumstances, be desirable for State organizations, such as that of the New York Cabinet of Natural History, to offer premiums for the best collections in particular departments of natural history, (within the State,) with the privilege of taking the others offered at a fair valuation. This would excite a spirit of emulation between societies and individuals, which could not fail of beneficial results, independently of the value of the collections themselves. The credit of having been the first to propose this plan in America is, perhaps, due to the Ottawa Atheneum, of *Ottawa, Canada,* which* has offered premiums of from two to ten pounds, amounting in the aggregate to £33 10s.

F—*Distribution of Collections.*

With increasing materials at its command, the Institution is able to do more and more in furnishing the means of scientific research to naturalists at home and abroad, either as an absolute donation or as an exchange for specimens received or promised. More assistance of this kind has been rendered in 1855 than in any previous year. Thus many specimens of American turtles and terrapins have been sent to Professor Agassiz to aid him in preparing materials for the first volume of his great work on American zoölogy. To Dr. J. Wyman also have been sent specimens of lophoid fishes and Perennia branchiate reptiles, to be used in his investigations. *Coleoptera* have been sent to J. L. Leconte, mammals to Major LeConte, eggs of birds to Dr. T. M. Brewer, infusorial earths to Professor Bailey, plants to Drs. Torrey and Gray.

A collection of 21 species of North American serpents was sent to the Jardin des Plantes, of Paris, embracing a number not previously in its possession. Many living specimens were also sent, but unfortunately lost, in a manner previously referred to. Duplicates of collections received have also been sent to institutions in this country, as fishes, birds and mammals to the Philadelphia Academy of Natural Sciences, fishes to the medical department of Pennsylvania University, mammals to the Boston Society of Natural History, &c.

G—*Exchange of Specimens.*

Much has been done by the Institution in 1855, as in preceding years, in the way of facilitating the labors of naturalists, by bringing into communication those of like tastes in different parts of this country, or the world. Many persons have thus been enabled to secure important additions to their means of research. Its extensive lists of workers in natural science throughout the world enables the Institution readily to meet the wishes of parties, by referring at once to those most likely to assist in accomplishing some special object.

Among the gentlemen who are desirous of having their wishes made known to fellow-workers in science, may be mentioned the following:

M. Zanardini, of Venice, desires to exchange specimens of Medi-

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* Journal of Education for Upper Canada, (Toronto,) November, 1855, page 175.

terranean and other European algae for specimens from North America.

W. A. Thomas, of Irvington, Westchester county, New York, desires to exchange minerals and fossils of New York for those of other States.

James Lewis, of Mohawk, New York, is prepared to exchange shells of New York for others from the south and west.

B. Pybas, of Tuscumbia, Alabama, will exchange shells of the Tennessee river for Silurian and Tertiary fossils.

Frank Higgins, of Columbus, Ohio, will exchange Ohio shells for those of southern States.

Dr. Emile Cornaria, Assistant Director of the Civic Museum, Milan, will exchange vertebrata, mollusca, insects, and fossils of Italy, Hungary, &c., for corresponding specimens from America.

H—*List of Additions to the Museum of the Smithsonian Institution in* 1855.

Dr. R. P. Abbott, U. S. A.—Reptiles from near Fort Yuma, California.

Professor L. Agassiz.—Fresh-water fish from China; mammals from Massachusetts and Lake Superior.

Dr. W. W. Anderson.—Living deer and antelope from Texas. Specimens of destructive insects (*Spenophorus*) from South Carolina.

Dr. W. W. Anderson, U. S. A.—Reptiles, fishes, and young beaver in alcohol, from Texas.

Professor E. B. Andrews.—Reptiles from western Louisiana. Deposited.

Seth Andrews.—Infusorial earth from Olympia, Washington Territory.

Dr. W. O. Ayres.—Fishes and scalops from San Francisco.

S. F. Baird.—Collections of fishes and reptiles made at Elizabethtown, Saranac Lake, Ogdensburg, and Madrid. Thirty skins of mammals from northern New York. Living racoon from California.

Thomas Barnett.—Minerals and fossils from Niagara Falls.

Dr. J. B. Barratt.—Skin of *scalops*, and two boxes of insects from South Carolina.

A. C. Barry.—Mammals and fishes from Wisconsin.

John G. Bell.—Polar hare (*Lepus glacialis*) and mounted quail, (*Ortyx virginianus.*) Specimens in flesh of the varying hare of New York, (*Lepus americanus.*)

J. Jacob Bower.—Specimen in flesh of black swan of Australia, Barnacle goose, and blue-headed pigeon from his aviary.

Dr. T. M. Brewer.—Mammals in alcohol from Massachusetts.

J. L. Bridger.—Keg of mammals and reptiles, skins of squirrels and hares, from North Carolina.

Solomon G. Brown.—Mammals from vicinity of Washington.

A. Campbell.—Two foetal black-tail deer from California.

Major J. H. Carleton, U. S. A.—Seeds of grass from the Pecos river.

Captain J. B. Casey, U. S. A.—Tail of a ray, (Tampa Bay.)

Rollin R. Child.—Skin of *Vespertilio noveboracensis*, from Wisconsin.

George Clarke.—Box of fresh white fish (*Coregonus*) from Lake Erie, in ice. Barrel of fishes in alcohol from the Maumee river.

James Clarke.—Specimens of Stickleback from England.

Robert Clarke.—Skulls of wolf and moose from northern New York.

Dr. J. G. Cooper.—Skins of mammals, birds, and case of specimens in alcohol, Shoalwater bay. Mammals from Santa Clara, California.

Lieut. D. N. Couch, U. S. A.—Box of mammals and birds, Kansas.

Rev. M. A. Curtis, Armand D. R. Curtis, and M. Ashley Curtis.—Numerous skins of mammals and birds, eggs of birds, reptiles in alcohol, from North and South Carolina.

R. D. Cutts.—Skins of birds and mammals, with reptiles and fishes in alcohol, from San Francisco county, California.

H. Davis.—Nests and eggs of birds, mammals in alcohol, from New York.

J. W. Dawson.—Specimens of *Jaculus*, *Arviola*, and *Sorex*, from Nova Scotia. Deposited.

E. A. Dayton.—Keg of fishes (crooked mullet) from Grass river, New York.

Samuel A. Dewey.—Chalcedony and Itacolumite from North Carolina.

W. A. Dougal.—Living mole, (*Scalops aquaticus.*)

Dr. John D. Easter.—Salamander and gryllotalpa from Germany.

Dr. George Engelmann.—Mammals, reptiles, and crustacea from Missouri.

Professor L. C. Ervendberg.—Collection of plants from Comal county, Texas.

S. B. Erwin.—Slab of Itacolumite from Burke county, North Carolina.

Dr. John Evans.—Can of reptiles and fishes from Upper Missouri. Pair of living wild cats.

Dr. J. Evans and Wm. P. Hendricks.—Living grizzly bear from Upper Missouri.

Dr. Eversfield.—Nut of double cocoanut, (*Lodoicea seychellana.*)

Rev. Frederick Fitzgerald.—Reptiles in alcohol. Skin of barred owl (*Strix nebulosa*) from North Carolina.

Dr. E. Foreman.—Two sets of minerals.

A. Galbraith.—Skin of purple sand-piper, (*Tringa maritima,*) Philadelphia.

C. Gautier.—Living deer mouse, (*Hesperomys.*)

Dr. Rodney Glisan, U. S. A.—Bale of dried plants, Fort Arbuckle.

J. M. Gilliss, U. S. N.—Box of birds from Chili.

Mr. Goldsboro.—Living *Heterodon platyrhinos* from Virginia.

Mr. P. Grant.—Blind-fish and crab, *Amblyopsis spelaeus*, and *Cambarus pellucidus*, from Mammoth cave, Kentucky.

James T. Gulick.—Skin of *metarenia* from Sandwich Islands.

Dr. S. E. Hale.—Two fresh specimens of pine martin or sable (*Mustela huro*) from northern New York.

Dr. J. F. Hammond, U. S. A.—Box of mammals, reptiles, fishes, &c., from Fort Reading, California.

Dr. W. A. Hammond, U. S. A.—Bottle of insects from Kansas.

Mr. Harvey.—Specimens of reptiles, fishes, and fossils from the Upper Missouri.

Master Herder.—Irish specimen of Baltimore oriole, (*Icterus Baltimore.*)

Dr. Hilgard.—Skeletons of *Astur cooperi* and *Sciurus migratorius* (grey squirrel) from Missouri.

Dr. Hilgard.—Three boxes dried European plants. Deposited.

Robert Howell.—Mammals, reptiles, and fishes of New York.

Dr. P. R. Hoy.—Skull of *Spermophilus franklinii*, and many skins of mammals, from Wisconsin.

Jardin des Plantes.—Collection of Mexican serpents, types of species described in Erpetologie genérale.

Sir Wm. Jardine.—Skins of weasels, foxes, hares, and arvicolas from Scotland.

J. W. P. Jenks.—Over 600 specimens of small mammals of Massachusetts in alcohol, and 120 skins.

Dr. C. J. B. Karsten.—Specimens of meteoric iron from Thorn, Prussia.

George Kennicott.—Box of birds' eggs from Illinois.

Robert Kennicott.—Several collections of living reptiles, about 200 in number; reptiles, fishes, and mammals in alcohol; dried skins of mammals; eggs of birds; specimens of seventeen-year locusts; living grey gopher, *Spermophilus franklinii*, &c., from Illinois.

J. Kirkpatrick.—Living *Nerodia nigra* from Lorain county, Ohio.

C. F. Kirtland.—Fishes and reptiles from Ohio.

Professor J. P. Kirtland.—Seven skins of mammals from Ohio.

Mr. Kniesley.—Eight hundred small mammals from Clarke county, Virginia, in alcohol.

Th. Kümlien.—Five skins of birds from Wisconsin. Skin of *Sorex brevicaudus.*

Geo. N. Lawrence.—Skins of *Sciurus* and *Sorex* from Iowa, of *Arvicola* and *Sorex* from New York.

Major Le Conte.—Skin of *Reithrodon lecontii* from Georgia.

Leo. Lesquereux.—Salamanders from Ohio.

J. Lewis.—Shells from New York.

Marshall MacDonald.—Living deer mouse (*Hesperomys*) from Virginia.

Dr. A. Means.—Specimens of *Polyodon* from Tennessee.

Montreal Society of Natural History.—Skin of *Hesperomys* from Canada.

W. E. Moore and A. J. Stevens.—Mammals, fishes, and salamander from Iowa.

Dr. James Morrow.—Five skins of *Hesperomys aureolus* from South Carolina.

R. J. Napper.—Box of bird-skins from Manilla.

H. M. Neisler.—Fifteen specimens of shells from the Chattahooche river.

Dr. Nichols.—Mammals in flesh from vicinity of Washington. Two specimens of *Crax* and *Nasua* in flesh from Paraguay.

Geo. W. Oakley.—Box of pyntiferous rock from Cayuga county, New York.

Captain W. P. Palmer, U. S. A.—Specimens of *Heterodon platyrhinos* from Virginia.

W. Patten.—Skin of *Mus rattus* from Pennsylvania.

Lieut. T. E. Patterson, U. S. A.—Double-headed rattlesnake from Camp Yuma.

D. Orrin Plumb.—Box of infusorial earth ; specimens in alcohol of fishes ; skull of rattlesnake ; specimen of gibbsite.

Professor F. Poey.—Fishes from Cuba.

James P. Postell.—Eggs of birds and reptiles from Georgia.

John Potts.—Reptiles and fishes in alcohol; skins of mammals and birds from Mexico.

B. Pybas.—Reptiles, fishes, and fossils from Alabama.

Thomas Rainey.—Fishes (*Callichthys* and *Osteoglossum*) from Para.

Edward Ravenel.—Box of recent and fossil shells of Carolina, including *Encope macrophora*, *Mellita ampla*, and *caroliniana.*

Carrington Raymond.—Australian Boomerang club and satchel.

Commander C. Ringgold, U. S. N.—Bow and four bone-tipped arrows—island of Nitenda.

Wynaham Robertson.—End of lower jaw of young mastodon from Washington county, Virginia.

E. S. Robinson.—Insects from Mississippi.

F. Schafhirt.—Separated human skull.

F. D. Sergeant.—Living specimens of bull-snake (*Pityophis sayi*) and jar of reptiles from Illinois.

W. J. Shaw.—Mammals, birds, insects and plants from Illinois.

Dr. Short, Lieut. D. N. Couch, and *Professor A. Gray.*—Set of plants of Mexico and Texas from the Berlandier collection.

Dr. B. F. Shumard.—Reptiles and fishes from Missouri.

Dr. Wm. Spillman.—Fishes, reptiles, shells, and fossils from Mississippi.

F. Sturm.—Skins, nests, and eggs of birds ; skins and skulls of mammals from Europe.

Dr. George Suckley, U. S. A.—Very large collections of mammals, birds, reptiles, fishes, and invertebrates from Washington and Oregon Territories. Living serpent, *Epicrates maurus,* from Panama.

A. S. Taylor.—Dried specimens of grasshopper, and of *Talitrus,* from California.

Major G. H. Thomas, U. S. A.—Box of river sediment, &c., from the Colorado river.

Professor Z. Thompson.—Skins of mammals and alcoholic specimens from Vermont.

Dr. W. F. Tolmie.—Skulls of birds from the Pacific.

General Totten, U. S. A.—Two cabinets containing a large collection of shells. Deposited.

Lieut. W. P. Trowbridge, U. S. A.—Box of birds and mammals from San Diego, California, collected by Andrew Cassidy; collection of muds from San Diego; skins of mammals collected in Oregon by Job Wayne; box of marine plants; two boxes mammals and birds, collected by T. A. Szabo; keg of reptiles and fishes from coast of California; other collections, in alcohol, from Cape Flattery and Farralones; box of shells, La Paz, &c.

N. Trübner.—Collection of 150 slides from the microscope, exhibiting dissections, illustrating different families of insects; also 25 miscellaneous slides prepared by H. Frey.

Col. Joseph Tuley.—Fresh skin of elk (*Elaphus Canadensis*) from his park.

Colonel Alfred Vaughan and Dr. F. V. Hayden.—Skins and skulls; mammals and birds; reptiles and fishes in alcohol; box of fossils, from Upper Missouri.

Gen. Ward.—*Heterodon niger* from Sing Sing, New York.

David Welsh.—Skins of squirrels (*Tamias* and *Sciurus*) from New York.

Plowden C. J. Weston.—Reptiles and birds in alcohol; fishes from South Carolina; fern in alcohol.

Dr. Wilson, U. S. A.—Shells from Japan.

Dr. T. G. Wormley.—Reptiles and fishes from Ohio.

Lieut. H. G. Wright, U. S. A., and Dr. D. D. Whitehurst.—Fishes and invertebrates from Tortugas.

Gustavus Würdemann.—Eggs and skins of birds, reptiles, fishes, and invertebrates, in alcohol; pair of living roseate spoonbills, (*Platalea Ajaja,*) from Indian river, Florida, and coast of Georgia and South Carolina.

Professor J. Wyman.—*Arviciola*, *Sorex*, and *Cyclopterus*, from Labrador. *Scaphiopus holbrookii* from Cambridge. Deposited.

LIST OF METEOROLOGICAL OBSERVERS.

State.	Name of observer.	Residence.	County.
Nova Scotia	Henry Poole	Albion Mines	Pictou.
	Prof. A. P. S. Stuart	Horton, Acadia College.	
Canada	Dr. Charles Smallwood	St. Martin	Laval.
	Dr. A. Hall	Montreal	
Maine	J. D. Parker	Steuben	Washington.
	Henry Willis	Portland	Cumberland.
	W. E. Dana	Perry	Washington.
	George B. Barrows	Fryeburg	Oxford.
	John J. Bell	Carmel	Penobscot.
	R. H. Gardiner	Gardiner	Kennebec.
	Rev. S. H. Merrill	Bluehill	Hancock.
	Samuel A. Eveleth	Windham	Cumberland.
	G. W. Guptill	Cornish	York.
New Hampshire	B. Gould Brown	Stratford	Coos.
	Dr. William Prescott	Concord	Merrimac.
	R. C. Mack	Londonderry	Rockingham.
	Samuel N. Bell	Manchester	Hillsboro'.
	R. F. Hanscom	North Barnstead	Belknap.
	Henry A. Sawyer, A. M	Great Falls	Strafford.
	Rev. L. W. Leonard	Exeter	Rockingham.
Vermont	D. Buckland	Brandon	Rutland.
	James A. Paddock	Craftsbury	Orleans.
	J. C. Baker	Saxe's Mills	Franklin.
	A. Jackman	Norwich	Windsor.
	George Bliss	Shelburne	Chittenden.
	James K. Colby	St. Johnsbury	Caledonia.
Massachusetts	Lucius C. Allin	Springfield	Hampden.
	William Bacon	Richmond	Berkshire.
	John Brooks	Princeton	Worcester.
	Rev. Emerson Davis	Westfield	Hampden.
	Amasa Holcomb	Southwick	Hampden.
	James Orton Lavalette Wilson	Williamstown	Berkshire.
	Hon. William Mitchell	Nantucket	Nantucket.
	Prof. E. S. Snell	Amherst	Hampshire.
	H. C. Perkins, M. D	Newburyport	Essex.
	Edward A. Smith, M. D. Frank H. Rice, M. D	Worcester	Worcester.
	Samuel Rodman	New Bedford	Bristol.
	John George Metcalf	Mendon	Worcester.
	Henry Rice	North Attleboro'	Bristol.
	Albert Schlegel	Taunton	Bristol.
	W. C. Bond	Cambridge	Middlesex.
	R. R. Gifford	Wood's Hole	Barnstable.
Rhode Island	Prof. A. Caswell	Providence	Providence.
	E. G. Arnold	East Greenwich	Washington.
Connecticut	Rev. T. Edwards	New London	New London.
	D. Hunt	Pomfret	Windham.
	Aaron B. Hull	Georgetown	Fairfield.
	James Rankin	Saybrook	Middlesex.
	N. Scholfield	Norwich	New London.
New York	Prof. O. W. Morris	New York	New York.
	Thos. B. Arden	Beverly	Putnam.
	E. W. Johnson	Canton	St. Lawrence.
	Ephraim Byram	Sag Harbor	Suffolk.
	John Lefferts	Lodi	Seneca.
	Wm. S. Malcolm	Oswego	Oswego.
	John Bowman	Baldwinsville	Onondaga.

METEOROLOGICAL LIST—Continued.

State.	Name of observer.	Residence.	County.
New York—Cont.	W. E. Guest	Ogdensburgh	St. Lawrence.
	A. W. Morehouse	Spencertown	Columbia.
	J. Everett Breed	Smithville	Jefferson.
	Rev. W. D. Wilson	Geneva	Ontario.
	P. O. Williams, M. D	Watertown	Jefferson.
	W. W. Sanger, M. D	Blackwell's Island	New York.
	John Felt	Liberty	Sullivan.
	J. W. Chickering	Ovid	Seneca.
	E. M. Alba, M D	Angelica	Alleghany.
	Prof. C. Dewey	Rochester	Monroe.
	Wm. C. Pratt		
	Joseph W. Taylor	Plattsburg	Clinton.
	Edw. C. Reed	Homer	Cortland.
	W. H. Denning	Fishkill Landing	Dutchess.
	Mrs. M. J. Lobdell	North Salem	Westchester.
	E. A. Dayton	Madrid	St. Lawrence.
	John R. French	Mexico	Oswego.
	Stephen Landon	Eden	Erie.
	S. De Witt Bloodgood	New York	New York.
	J. S. Gibbons		
	J. Caroll House	Lowville	Lewis.
	Dr. H. P. Sartwell	Penn Yan	Yates.
	Rev. Thos. H. Strong	Flatbush	Kings.
	Stillman Spooner	Wampsville	Madison.
New Jersey	R. L. Cooke	Bloomfield	Essex.
	Dr. E. R. Schmidt	Burlington	Burlington.
	W. A. Whitehead	Newark	Essex.
Pennsylvania	Joseph Edwards	Chromedale	Delaware.
	Rev. Grier Ralston	Norristown	Montgomery.
	John Heisely	Harrisburg	Dauphin.
	M. Jacobs	Gettysburg	Adams.
	Fenelon Darlington	Pocopson	Chester.
	Samuel Brown	Bedford	Bedford.
	Ebenezer Hance	Morrisville	Bucks.
	Paul Swift	Haverford	Philadelphia.
	Francis Schreiner	Moss Grove	Crawford.
	Chas. S. James	Lewisburg	Union.
	J F. Thickstun	Meadville	Crawford.
	W. W. Wilson	Pittsburg	Alleghany.
	O. T. Hobbs	Randolph	Crawford.
	Wm. Smith	Canonsburg	Washington.
	John Eggert	Berwick	Columbia.
	H. A. Brickenstein	Nazareth Hall	Northampton.
	Prof. Jas. A. Kirkpatrick	Philadelphia	Philadelphia.
	Prof. W. C. Wilson	Carlisle	Cumberland.
	Victor Scriba	Troy Hill	Alleghany.
	Jno. Hastings	Pittsburg	Alleghany.
	Wm. Martin		
	A. Heger	Pottsville	Schuylkill.
Delaware	Professor W. A. Crawford	Newark	Newcastle.
	R. A. Martin		
Maryland	Miss H. M. Baer	Sykesville	Carroll.
	Henry E. Hanshaw	Frederick	Frederick.
	B. O. Lowndes	Bladensburg	Prince George.
	James A. Pearce, jr	Chestertown	Kent.
	A. Zumbrock, M. D.	Annapolis	Anne Arundel.
Virginia	Lieut. R. F. Astrop	Crichton's Store	Brunswick.
	Samuel Couch	Buffalo	Putnam.
	Benjamin Hallowell	Alexandria	Alexandria.

METEOROLOGICAL LIST—Continued.

State.	Name of observer.	Residence.	County.
Virginia—Cont'd	D. H. Ellis	Wardensville	Hardy.
	James T. Clarke	Mount Solon	Augusta.
	J. W. Marvin	Winchester	Frederick.
	Thomas Patton	Lewisburg	Greenbrier.
	W. C. Quincy	West Union	Doddridge.
	Miss E. Kownslar	Berryville	Clark.
	William Skeen	Huntersville	Pocahontas.
	Prof. N. B. Webster	Portsmouth	Norfolk.
North Carolina	Prof. Dan. Morelle	Goldsborough	Wayne.
	Prof. James Phillips	Chapel Hill	Orange.
South Carolina	E. N. Fuller	Edisto Island	Colleton.
	Rev. A. Glennie	Waccaman	All Saints Parish.
	Dr. Jos. Johnson	Charleston	Charleston.
	H. W. Ravenel	Aiken	Barnwell.
	T. A. Young, M.D.	Camden	Kershaw.
Georgia	Dr. James Anderson	The Rock	Upson.
	R. P Gibson	Whitemarsh Island	Chatham.
	F. M. Pendleton	Sparta	Hancock.
	John F. Posey	Savannah	Chatham.
	W. Haines	Augusta	Richmond.
Florida	Dr. A. S. Baldwin	Jacksonville	Duval.
	James B. Bailey	Garrisville	Alachua.
	William C. Dennis	Salt Ponds	Island Key West.
	Lieut. Jos. Fry	Pensacola	Escambia.
	John Pearson		
	Hon. Augustus Steele	Cedar Keys	Levy.
Alabama	George Benagh	Tuscaloosa	Tuscaloosa.
	S. J. Cumming	Monroeville	Monroe.
	Prof. John Darby	Auburn	Macon.
	H. Tutwiler	Green Springs	Green.
Mississippi	Prof. J. Boyd Elliott	Port Gibson	Claiborne.
	Prof. L. Harper	Oxford	Lafayette.
	James S. Lull	Columbus	Lowndes.
	Rev E. S. Robinson	Garlandsville	Jasper.
Louisiana	Dr. E. H. Barton	New Orleans	Orleans.
Texas	J. L. Forke	New Wied	Comal.
	S. K. Jennings, M. D	Austin	Travis.
Tennessee	Dr. R. T. Carver	Friendship	Dyer.
	T. L. Griswold	Knoxville	Knox.
	William M. Stewart	Glenwood	Montgomery.
Kentucky	O. Beatty	Danville	Boyle.
	L. G. Ray, M. D.	Paris	Bourbon.
	George S. Savage, M. D	Millersburg	Bourbon.
	John Swain, M. D	Ballardsville	Oldham.
	Mrs. Lawrence Young	Springdale	Jefferson.
Ohio	Prof. J. W. Andrews	Marietta	Washington.
	R. S. Bosworth	College Hill	Hamilton.
	F. A. Benton	Mount Vernon	Knox.
	George L. Crookham	Jackson C. H.	Jackson.
	M. Gilmore		
	Miss Ardelia Cunningham	Unionville	Lake.
	Jacob M. Desellem	Richmond	Jefferson.
	L. M. Dayton	Newark	Licking.
	J. H. Fairchild	Oberlin	Loraine.
	L. Groneweg	Germantown	Montgomery.
	Geo. W. Harper	Cincinnati	Hamilton.
	Ebenezer Hannaford	Cheviot	Hamilton.
	James D. Herrick	Jefferson	Ashtabula.
	F. Hollenbeck	Perrysburg	Wood.

METEOROLOGICAL LIST—Continued.

State.	Name of observer.	Residence.	County.
Ohio—Continued	J. G. F. Holston, M. D	Zanesville	Muskingum.
	G. A. Hyde	Cleveland	Cuyahoga.
	S. L. Hillier	Hiram	Portage.
	S. M. Luther		
	John Ingram, M. D	Savannah	Ashland.
	G. W. Livezay	Gallipolis	Gallia.
	J. McD. Mathews	Hillsborough	Highland.
	James H. Poe	Portsmouth	Scioto.
	Prof. S. N. Sanford	Granville	Licking.
	Joseph Shaw	Bellefontaine	Logan.
	W. L. Schenck, M. D	Franklin	Warren.
	Prof. M. G. Williams	Urbana	Champaign.
Michigan	Seth L. Andrews, M. D	Romeo	Macomb.
	Wm. Campbell	Battle Creek	Calhoun.
	Alfred E. Currier	Grand Rapids	Kent.
	Rev. George Duffield	Detroit	Wayne.
	L. H. Strang	Saugatuck	Alleghany.
	J. J. Strang	St. James	Michilimackinac.
	Isaac Stone	Romeo	Macomb.
	Miss Octavia C. Walker	Cooper	Kalamazoo.
	H. Whelpley	Monroe	Monroe.
	Lum Woodruff	Ann Arbor	Washtenaw.
	Prof. A. Winchell		
Indiana	W. W. Austin	Richmond	Wayne.
	C. Barnes	New Albany	Floyd.
	John Chappellsmith	New Harmony	Posey.
	Dr. V. Kersey	Milton	Wayne.
	Joseph Moore	Richmond	Wayne.
Illinois	Dr. Fr. Brendel	Peoria	Peoria.
	Wm. V. Eldredge	Brighton	Macoupin.
	John Grant	Manchester	Scott.
	Joel Hall	Athens	Menard.
	J. O. Harris, M. D	Ottawa	La Salle.
	John James, M. D	Upper Alton	Madison.
	S. B. Mead, M. D	Augusta	Hancock.
	Henry A. Titze	West Salem	Edwards.
	Benj. Whitaker	Warsaw	Hancock.
Missouri	Chas. Q. Chandler, M. D	Rockport	Boone.
	Edw. Duffield, M. D	Hannibal	Marion.
	Geo. Engelmann, M. D	St. Louis	St. Louis.
	O. H. P. Lear	Dry Ridge	Marion.
Iowa	E. C. Bidwell, M. D	Quasqueton	Buchanan.
	Townsend M. Connel	Pleasant Plain	Jefferson.
	Dr. Asa Horr	Dubuque	Dubuque.
	Daniel McCready	Fort Madison	Lee.
	Benj. F. Odell	Plum Spring	Delaware.
	Mary G. Odell		
	T. S. Parvin	Muscatine	Muscatine.
	E. H. A. Scheeper	Pella	Marion.
Wisconsin	Miss M. E. Baker	Ceresca	Fond du Lac.
	Prof. S. A. Bean	Waukesha	Waukesha.
	John E. Himoe	Norway	Racine.
	Wm. H. Newton	Superior	Douglas.
	L. Washington		
	J. L. Pickard	Platteville	Grant.
	Prof. Wm. Porter	Beloit	Rock.
	F. C. Pomeroy	Milwaukie	Milwaukie.
	J. F. Willard	Janesville	Rock.
	Carl Winkler	Milwaukie	Milwaukie.

METEOROLOGICAL LIST—Continued.

State.	Name of observer.	Residence.	County.
Minnesota	S. R. Riggs	Hazlewood	
	D. B. Spencer	St. Joseph	Pembina.
California	Dr. H. Gibbons	San Francisco	San Francisco.
	Dr. F. W. Hatch Dr. Thos. M. Logan	Sacramento	Sacramento.
	Dr. Robert K. Reid	Stockton	San Joaquin.
H. B. Territory	Donald Gunn	Red River Settlem't	
Paraguay	E. A. Hopkins		
Mexico	Prof. L. C. Ervendberg		
Jamaica	James G. Sawkins		
Nicaragua	J. Moses		
Venezuela	A. Fendler		

REPORT OF THE EXECUTIVE COMMITTEE.

WASHINGTON, *January* 1, 1856.

The Executive Committee submit to the Board of Regents the following report relative to the finances of the Smithsonian Institution, the expenditures during the year 1855, &c.

The following is a general statement of the fund:

The whole amount of the Smithsonian bequest deposited in the treasury of the United States, (from which an annual income, at 6 per cent., of $30,910 14 is derived,) is		$515,169 00
Amount of unexpended interest reported, 1855, January 1, as in charge of Messrs. Corcoran & Riggs	$125,000 00	
From which deduct amount passed by them to the credit of the treasurer to meet payments on building during 1855	5,000 00	
	120,000 00	
Balance in the hands of the treasurer, 1st January, 1856	8,189 84	
		128,189 84
		643,358 84

The following is a general view of the receipts and expenditures during the year 1855:

RECEIPTS.

Balance in the hands of the treasurer, January 1, 1855	$14,159 59	
Interest on the original fund ($515,169) for 1855	30,910 21	
Interest on the extra fund for the year 1855	6,044 38	
Amount drawn from Corcoran & Riggs to meet payments on building	5,000 00	
		$56,114 18

EXPENDITURES.

For building, furniture, fixtures, &c.	$19,312 87	
For items common to the objects of the Institution	13,372 71	
For publications, researches, and lectures	7,169 95	
For library, museum, and gallery of art	8,068 81	
		$47,924 34

Balance in the hands of the treasurer, on the 1st of January, 1856	$8,189 84
	56,114 18

The following is a detailed statement of the expenditures during the year 1855:

BUILDING, FURNITURE, FIXTURES, &C.

Pay on contracts	$16,200 00	
Pay of architects, draughtsmen, &c	500 00	
Miscellaneous repairs to building, &c	436 90	
Furniture and fixtures for uses in common	1,488 04	
Furniture and fixtures for library	400 00	
Furniture and fixtures for museum	200 00	
Grounds (lamps for the walks)	74 25	
Magnetic observatory	13 68	
		$19,312 87

GENERAL EXPENSES.

Meetings of the Board of Regents and committees	849 65	
Lighting and heating	1,022 80	
Postage	495 41	
Transportation and exchange	1,103 23	
Stationery	411 98	
General printing	827 55	
Apparatus	257 06	
Laboratory	123 14	
Incidentals, general	1,257 16	
Salaries—Secretary	3,500 00	
Chief clerk	1,200 00	
Book-keeper	200 00	
Janitor	400 00	
Laborer	250 00	
Watchman	365 00	
Extra clerks	250 00	
		12,512 98

PUBLICATIONS, RESEARCHES, AND LECTURES.

For Smithsonian Contributions to Knowledge	3,562 92	
For reports on progress of knowledge	350 00	
For other publications	316 83	
For meteorology	1,862 28	
For computations	50 00	
For investigations	12 50	
For lectures, illustrations, and apparatus	40 66	
attendance, &c	60 76	
pay of lecturers	914 00	
		7,169 95

LIBRARY, MUSEUM, AND GALLERY OF ART.

Library:		
Cost of books	$3,186 15	
Transportation for library	330 49	
Stereotype system	44 22	
Pay of assistants	1,740 00	
Incidentals to library	124 31	
Museum:		
Salary of assistant secretary	2,000 00	
Explorations	150 00	
Collections	150 50	
Alcohol, glass jars, &c	199 88	
Assistance, labor, and incidentals to museum	390 57	
Transportation for museum	529 24	
Gallery of Art	83 18	
		$8,928 54
		47,924 34

It will be seen, from the foregoing statement, that the expenditures for the building differ considerably from the estimate of the committee. At the time of making the estimate, they had no means of ascertaining what would be required for payment of the contractor. The architect had not furnished his final statement of the entire cost of the edifice, and it was in consideration of this that a resolution was adopted, authorizing the Building Committee to pay out of the special fund of the Institution such sum as would be required. They have accordingly drawn $5,000 on this account from Messrs. Corcoran & Riggs, as is shown in the general statement.

On account of the large drafts required for payments on the building, an effort was made to curtail the expenditures on other parts of the operations. The whole sum appropriated for the current expenses of the Institution during the year 1855, exclusive of the building, was $32,465. Of this sum there has been expended but $28,611 47; the remainder, $3,853 53, serves to increase the amount in the hands of the treasurer, and will be appropriated to discharging the sum still due the contractor.

Hereafter the funds of the Institution will be in a much more manageable condition. The architect has rendered his final account, and the sum of about $6,000 still due on the building being definitely known, a more precise estimate can be now made. If the expenditures during the present year are kept within the estimate, as they probably will be, the sum of $125,000 of accrued interest will be on hand at the beginning of 1857, which may be permanently invested as a part of the capital.

It has been stated, in the preceding reports, that a plan of finances was adopted in the beginning, by which a portion of the income might be saved for the purpose of increasing the capital rendered necessary to defray the expense of the support of the large building authorized by Congress. It was at first proposed to add $100,000 to the original fund; and afterwards the plan was enlarged, so as to make the amount $150,000. This last plan, however, was based upon a limit of expenditure of $250,000 for the building. The scheme would have been entirely successful, and even a larger saving might have been made had the building been completed within the estimated cost; but this was found inconsistent with a proper regard to the safety and durability of the edifice. The actual cost, according to the statement of the Building Committee, exclusive of furniture, is about $310,000; notwithstanding this, the sum which has been saved is $125,000. Although this is not all that could have been wished, it is, perhaps, more than could have been reasonably anticipated. The committee have been informed that Messrs. Corcoran and Riggs do not desire any longer to retain possession of the surplus fund, and it will therefore be necessary to urge its acceptance by Congress as an addition to the fund in the United States treasury, or securely invest it in State stocks. The interest on the original fund is received semi-annually, and as far as possible it will be advisable to make the payments of salaries and other objects at the same time. Unless this is done, a surplus will continually be required which is not drawing interest, or bills must be paid by drafts in anticipation of the end of the half year. While the building was in process of erection, it was impossible to observe a rule of this kind, since, according to the original contract, the payments for the work done were to be made monthly.

It will be recollected that a portion of the Smithsonian bequest (about $25,000) still remains in England as the principal of a life annuity in favor of Madame de la Batut, the mother of the nephew of Smithson. The annuitant is a very aged person, and cannot in the ordinary course of nature be expected long to survive. The Hon. Mr. Rush, to whom this matter was referred, has written to Messrs. Clarke, Fynmore, & Fladgate, the solicitors employed in obtaining the bequest, asking them to procure information in regard to this point.

Another subject, which may require the attention of the Board, is that of the Wynn estate, contingently bequeathed to the Smithsonian Institution. It appears by a letter from Joseph H. Patton, esq., of New York, who was engaged by the Board to inquire into the matter, that the widow of Mr. Thomas Wynn was married in 1854 to Captain Anderson, of the Royal artillery, now stationed at Barbadoes, where she resides with the child, upon whose decease, without issue, the bulk of the estate is to come to this Institution.

Mr. Patton advises that the Board require from the executors security for the proper fulfilment of the trust.

The committee submit the following estimates for appropriations for the year 1856:

BUILDING, FURNITURE, FIXTURES, ETC.

Due on contracts	$6,000 00	
Repairs and miscellaneous incidentals to building	600 00	
Furniture, &c., for uses in common	500 00	
library	300 00	
museum	150 00	
Magnetic observatory	20 00	
		$7,570 00

GENERAL EXPENSES.

Meetings of Board and committees	$375 00	
Lighting and heating	1,200 00	
Postage	400 00	
Transportation and exchange	1,000 00	
Stationery	300 00	
General printing	350 00	
Apparatus	300 00	
Laboratory, fitting up	800 00	
Incidentals general	500 00	
Salaries—Secretary	3,500 00	
Chief clerk	1,200 00	
Book-keeper	200 00	
Janitor	400 00	
Watchmen	550 00	
Laborers	450 00	
Extra clerks	200 00	
		11,725 00

PUBLICATIONS, RESEARCHES, AND LECTURES.

Smithsonian Contributions to Knowledge	$5,500 00	
Reports on the progress of knowledge	1,000 00	
Other publications	355 00	
Meteorology	1,000 00	
Investigations, computations, and researches	500 00	
Lectures	800 00	
		9,155 00

LIBRARY, MUSEUM, AND GALLERY OF ART.

Library:	
Cost of books	$3,500 00
Pay of assistants	2,500 00
Transportation	300 00
Incidentals	500 00
Museum:	
Salary of assistant secretary	2,000 00
Explorations	200 00
Collections	150 00

Alcohol, glass jars, &c	$500 00	
Transportation	300 00	
Assistance and labor	500 00	
Gallery of Art	100 00	
		$10,550 00
		39,000 00

Respectfully submitted:

J. A. PEARCE,
J. G. TOTTEN,
A. D. BACHE,
Executive Committee.

REPORT OF THE BUILDING COMMITTEE.

The Building Committee of the Smithsonian Institution present the following report of their operations and expenditures during the year 1855:

It was stated in the last report that the main or centre building was nearly finished on the 1st of January, 1855. Since then the whole edifice has been completed, and the final report of the architect approved by the committee. After the construction of the new lecture-room, the east wing of the building was entirely unoccupied. It consisted of a single room 75 feet long, 45 feet wide, and about 30 feet high. This has been divided into two stories, the lower one principally consisting of a large room at present used for the reception and distribution of all the articles of exchange, and also a depository of the extra copies of the publications of the Institution. The upper story is occupied by a suite of rooms for the accommodation of the Secretary, in accordance with the original intention of the Board, as expressed in their resolution fixing the compensation of that officer. The fitting up of this wing was made under a separate contract with Mr. Wm. Choppin, and the whole completed to the satisfaction of the architect for $3,500. This sum includes both the finishing of the large room below and the apartments of the Secretary above.

The grounds around the building have been kept in repair under the direction of the Secretary of the Interior, and it is hoped that an appropriation by Congress will enable this officer to complete the design of Mr. Downing for the general improvement of the mall, and the supply of specimens of our native forest-trees which may be used for ornamental purposes.

The whole amount paid on account of the building during the last year, including furniture and fixtures and grounds, is $19,312 87, which added to the sum previously paid for the same objects as stated in the last report, ($299,414 14,) will make $318,727 01. Of this sum $308,184 49 are for the building and grounds; and if to this we add $4,569 10 due the contractor, and about $1,000 due on gas-fitting, fixtures, &c., the whole amount expended on building and grounds, exclusive of furniture, will be $313,753 59. The whole cost of the building was at one time limited to $250,000; but this limitation was made with the intention of finishing the interior of the main edifice in wood and plaster. This plan was afterwards abandoned, and one in which fire-proof materials were employed was substituted.

A statement on file from Capt. Alexander gives in detail the work done and the payments made thereon from the time he took charge of the work until its final completion. According to this, the whole amount paid for completing the interior of the main building in fire-proof materials is $79,684 17. This sum is much larger than his original estimate; the cause of the difference, as stated by himself, being as follows:

"It is due in part to the rise in the prices of materials and labor, but principally to the execution of many improvements which were not originally contemplated, but which it was thought best to make during the prosecution of the work. These improvements were the sewers for drainage; the cisterns for supplying water; the substitution of stone for iron stairs; the making of new sashes for many of the windows; the strengthening and in part reconstruction of the roof of the main building; putting in copper gutters and leaders on the towers, besides other alterations and additions tending to swell the cost of the work."

So many changes had been made in the plan of finishing the interior, and such different materials had been employed, that it was impossible to be guided by the original bid of the contractor, and therefore the committee were obliged to be governed entirely by the estimate of the architect. They, however, took the precaution to submit his award to Capt. Meigs, superintendent of the Capitol extension, who, under the circumstances of the case, expressed his approval of it.

Though the building is finished, an annual appropriation will be required for repairs and the substitution on parts of the roofs of the ranges and wings, of copper in place of tin.

Respectfully submitted;

RICHARD RUSH,
W. H. ENGLISH,
JNO. T. TOWERS,
JOSEPH HENRY,
Building Committee.

JOURNAL OF PROCEEDINGS
OF THE
BOARD OF REGENTS
OF
THE SMITHSONIAN INSTITUTION.

TENTH ANNUAL SESSION.

WEDNESDAY, January 2, 1856.

In accordance with a resolution of the Board of Regents of the Smithsonian Institution, fixing the time of the beginning of their annual meeting on the first Wednesday of January of each year, the Board met this day in the Regents' room at 12 o'clock m.

Mr. Rush was requested to take the chair.

The Secretary stated that, owing to the House of Representatives not having elected a speaker, no Regents had yet been appointed to fill the vacancies in the Board from that body.

There being no quorum present, the Board adjourned to meet on Saturday, January 12th, at 12 m.

SATURDAY, January 12, 1856.

A meeting of the Board was held this day at 12 o'clock.

Present: Messrs. Mason, Rush, Totten, Bache; Seaton, Treasurer, and the Secretary.

There being no quorum present, the new Regents not yet having been appointed, the Board adjourned to meet on Saturday, January 26th.

SATURDAY, January 26, 1856.

A meeting of the Board was held this day at 12 m.

Present: Messrs. Pearce, Mason, Rush, Totten, and the Secretary.

There being no quorum, the Board adjourned to meet at the call of the Secretary, as soon as the vacancies should be filled by Congress.

SATURDAY, March 1, 1856.

An adjourned meeting of the Board was held this day at 12 m.

Present: Messrs. Pearce, Mason, English, Warner, Totten; Seaton, Treasurer, and the Secretary.

Mr. Pearce was called to the chair.

The Secretary announced the election, by joint resolution of the Senate and House of Representatives, of the Hon. GEORGE E. BADGER, of North Carolina, and Professor CORNELIUS C. FELTON, of Massachusetts, as Regents to fill the vacancies occasioned by the death of the Hon. JOHN MACPHERSON BERRIEN, and the resignation of the Hon. RUFUS CHOATE.

Also, the appointment, by the Speaker of the House of Representatives, of the Hon. W. H. ENGLISH, of Indiana, Hon. H. WARNER, of Georgia, and the Hon. B. STANTON, of Ohio, as Regents on the part of the House.

Mr. Seaton, Treasurer, presented the statement of receipts and expenditures for the year 1855, which was referred to the Executive Committee.

The Secretary presented and read his report of the condition and operations of the Institution for the past year, which was accepted.

It being announced by the Secretary that the Hon. J. MACPHERSON BERRIEN, one of the Regents, had departed this life since the last annual session of the Board, Mr. Mason offered the following resolutions, accompanying them with remarks suitable to the occasion:

Resolved, That the Regents of the Smithsonian Institution have heard, with deep and sincere regret, that since their last annual meeting, the Hon. J. MACPHERSON BERRIEN, late one of their associates, has departed this life.

Resolved, That whilst deploring the severance of so enlightened and able a coadjutor from the trust committed to the Regents of the Institution, they sympathize with the country in the loss it has sustained by the death of an eminent and virtuous citizen.

Resolved, That, in testimony of their high respect for the memory of their late associate, the members of this Board will wear the customary badge of mourning for the period of thirty days.

Resolved, That these resolutions be entered upon the journal, and a copy of them be transmitted to the family of the deceased.

The Board then adjourned till Saturday, March 8th, at 11 o'clock a. m.

SATURDAY, MARCH 8, 1856.

The Board of Regents met at 11 o'clock a. m.

Present: The Chancellor, Hon. R. B. Taney, and Messrs. Pearce, English, Warner, Totten, and the Secretary.

The minutes of the last meeting were read and adopted.

Mr. English presented the report of the Building Committee for the year 1855; which was read and adopted.

Mr. Pearce presented the annual report of the Executive Committee, containing an account of the finances, the receipts and expenditures during the year 1855, the estimates for appropriations for 1856, &c.; which was read and adopted.

On motion of Mr. Pearce, the following resolution was adopted:

Resolved, That, in order to give sufficient time to make up the accounts for the year, the annual meeting of the Board shall hereafter be held on the *third* Wednesday of January, instead of the first.

The Secretary presented a letter from Joseph H. Patton, esq., of New York, relative to the Wynn estate; which, after several documents relating to the subject had been read, was referred to Mr. Mason, to whom former communications on this business had been submitted.

It was stated by the Secretary that Messrs. Corcoran & Riggs were not desirous to retain in their hands the extra funds of the Institution; whereupon, after remarks as to the proper disposition of the money, on motion of Mr. Warner, it was

Resolved, That the committee appointed on the 24th of February, 1855, be directed to inquire and report upon the propriety and manner of permanently investing the money of the Institution now in the hands of Messrs. Corcoran & Riggs.

The Secretary read a communication from Frederick Gotteri, of Malta, received through the Department of State, relative to the establishment of a school for the instruction of persons in this country in silk culture and manufactures.

On motion, the letter was referred to the Commissioner of Patents.

A communication from John Phillips, esq., assistant general secretary of the British Association for the Advancement of Science, was read, containing the following extract from the proceedings of that body:

"A communication from Professor Henry, of Washington, having been read, containing a proposal for the publication of a catalogue of philosophical memoirs scattered throughout the Transactions of societies in Europe and America, with the offer of co-operation on the part of the Smithsonian Institution, to the extent of preparing and publishing, in accordance with the general plan which might be adopted by the British Association, a catalogue of all the American memoirs on physical science, the committee approve of the suggestion, and recommend that Mr. Cayley, Mr. Grant, and Professor Stokes, be appointed a committee to consider the best system of arrangement, and to report thereon to the council."

The Secretary having stated to the Board that a number of the steamship and railroad companies had granted special facilities to the Institution, in forwarding its packages free of cost, and particularly in granting a free passage to its agent sent to California to make collections in natural history, &c.,

On motion of General Totten, the following resolution was adopted:

Resolved, That the Secretary, on the part of the Regents of the Smithsonian Institution, return thanks to the United States Mail Steamship Company, M. O. Roberts, president; Pacific Mail Steamship Company, W. H. Aspinwall, president; South American Mail Steamship Company, Don Juan Matheson, president; Mexican Gulf Steamship Company, Harris & Morgan, agents; and the Panama Railroad Company, David Hoagley, president, for their liberality and generous offices in relation to the transportation, without charge, of articles connected with the operations of the Institution.

The Secretary read the following letter:

HAMILTON COLLEGE, CLINTON,
Oneida County, N. Y., February 2, 1856.

To the Regents of the Smithsonian Institution:

The trustees of Hamilton College, in the State of New York, made, on the 22d day of July, 1854, a contract with Messrs. C. A. Spencer & Co., of Canastota, in the same State, for the construction of an "equatorial telescope of the first class, with all the mountings and other incidents necessary and usual thereto."

There is a provision in this agreement, that "when the telescope and work are finished and put up in the observatory, the whole is to be submitted to the examination of three men of science, to be agreed upon by the parties, and their judgment and decision as to the character of the telescope and the whole work, and whether the contract has been fully performed on the part of the builders, shall be final and conclusive."

The instrument is now nearly completed. The diameter of the object-glass is thirteen and one-half inches.

The undersigned, as a committee in behalf of the College, request that the above-named examining board of scientific men may be appointed by your body. They ask this for the following reasons:

First. This telescope is the largest ever constructed in this country—constructed in the face of many obstacles, with an adverse public opinion. If it be equal to instruments made in Europe, its construction is a triumph of American genius in a hitherto untried field. The contractors, if successful, deserve that their success should be made known through some medium whose judgment shall be rigid and impartial, and shall have a character to be respected abroad as well as at home.

Again. The funds for the construction of this instrument, and the observatory to which it is attached, were contributed in various sums by many persons interested in the advancement of science, and scattered throughout the State of New York. To these persons our institution pledged itself to secure a first-class instrument. The college corporation desires to satisfy them by an announcement from an authoritative quarter that it has faithfully fulfilled the trust, and that the contractors have produced the exact instrument provided for in the specifications of the contract.

Furthermore, as persons interested in the advancement of science, and desirous that telescopes hereafter built in this country may be thoroughly and satisfactorily tested, the undersigned, in behalf of the college, would be glad to establish a precedent, which might lead the purchasers of other astronomical instruments to submit the question of their proper construction to your body, as being an institution central in its position and national in its character.

We are authorized to state that the contractors join with the corporation in this application.

Should this proposition be accepted by you, we would like to receive notice to that effect, and of the names of the gentlemen who may be selected as such committee.

CHARLES AVERY,
ORIN ROOT,
OTHNIEL S. WILLIAMS,
THEODORE W. DWIGHT,
Committee.

On motion of Mr. English, the following resolution was adopted:

Resolved, That the letter of the committee of the trustees of Hamilton College be referred to Messrs. Bache, Totten, and Henry, with authority to comply with the request contained in said letter.

The following letter from the corresponding secretary of the American Academy of Arts and Sciences was read:

AMERICAN ACADEMY OF ARTS AND SCIENCES,
Boston and Cambridge, Massachusetts, August, 1855.

MY DEAR SIR: The following extract from the record of the annual meeting in May last has just been furnished me by the recording secretary:

"Professor Agassiz referred to the allusion in the librarian's report to the Smithsonian Institution, and expressed in strong language his sense of the indebtedness of the scientific world to that Institution, for its enlightened efforts to diffuse knowledge, particularly as a medium of exchange of publications. In conclusion, he moved *that the thanks of the academy be presented to the Smithsonian Institution, for its efficient agency in effecting for the academy its exchanges with societies and individuals*, which was unanimously adopted."

I have great pleasure in forwarding to you the vote of the academy, in obedience to its instructions.

And I remain, very respectfully, your obedient, faithful servant,

ASA GRAY,
Corresponding Secretary.

Professor HENRY,
Secretary of the Smithsonian Institution.

The Board then adjourned to meet on Saturday, the 22d instant, at 11 o'clock a. m.

SATURDAY, *March* 22, 1856.

The Board of Regents met this day, at 11 o'clock.

Present: Hon. R. B. Taney, the Chancellor, Messrs. Mason, Douglas, English, Warner, Totten, Towers; Seaton, Treasurer, and the Secretary.

The minutes of the last meeting were read and approved.

Mr. Mason stated that he had made an examination of the papers referred to him relative to the Wynn estate.

After some remarks respecting the proper course to be pursued, on motion of Mr. Douglas, it was

Resolved, That Messrs. Mason and English be appointed a committee to draught a bill, and present it to Congress at their discretion, asking the authority for the Institution to receive funds or legacies, and for power to sue and be sued.

The Secretary presented the subject of the removal of the collection of objects of natural history, now in the Patent Office, to the Smithsonian building.

The Secretary presented to the Board a manuscript work on bibliography by Mr. Ludewig, which had originally been offered to the Smithsonian Institution, but which Mr. Trübner, a liberal and intelligent publisher in London, had now undertaken to present to the world at his own expense.

The following letter from Mr. Stone, of Washington, was read:

MOUNT PLEASANT,
Washington City, February 13, 1856.

DEAR SIR: Some time since I spoke to you of the propriety and advantage of procuring from Europe copies in plaster of the best antique and modern statues and bas-reliefs. Having since reflected on the importance of cultivating a taste for the fine arts in our country, I now communicate to you my views, knowing that the object will find in you a zealous friend and advocate.

I am aware, to undertake what is required will subject you to some trouble and opposition, owing to the absence of that knowledge, to procure which your exertions are solicited.

As the country advances in science, the elegancies of life are in demand; decorations, ornaments, &c., in every fabric, find purchasers, and the higher the state of refinement, the more is art required. To meet this demand, it is requisite that we should have the advantage of seeing what has already been done in sculpture to serve as a basis. Thus, we may not only cultivate the talent of the artist, but the taste of the consumer, and thus the arts will meet with proper encouragement.

It is not expected that all who study from the models will acquire equal eminence; still all who work with zeal will be improved and find employment in the various branches of trade that require cultivated talent, as in works of design, including the various factories for using the loom for wool, cotton, or silk, potteries, including porcelain ware, foundries, &c. Painters, architects, and sculptors are usually thought to be those only benefited by schools of art; but it is not so: they are a few among the thousands who will be prepared to give beauty and elegance to every fabric of manufacture known in the mechanic arts.

On examination it will be found that the cultivation of the art of design will thus be of immense value to the country. On application being made by our minister in Rome, casts would be permitted to be taken from the moulds in the possession of the government, the cost of which would be trifling. The statues would decorate the Smithsonian building, and many could be so placed as to appear as accessories to it.

If a school of design is formed, it may be independent of the Institution. But should the Smithsonian Institution deem it of sufficient importance, and consider it as one of the means of diffusion of useful knowledge among men, and grant an occasional lecture as on other subjects, it would accomplish much, and Congress may be made to feel that the interests of the country demand their fostering care in regard to the arts. I think you will find that ours is the only government that has not seen and felt the importance to manufactures of cultivating the fine arts. The great strife with manufacturers is, to obtain elegance and beauty without interfering with durability. Beauty and symmetry should be made essentials in the manufacture of the simplest articles, as they may be attained without interfering with more substantial qualities. Articles manufactured with elegance and good proportion will always be preferred to those of only equal strength and durability, of uncouth form. It is true that we may manufacture from forms and patterns produced by the forethought and liberality of other nations, and still be inferior to what our own genius would produce, were the facilities of cultivation in the fine arts made equal with those of other nations. The free institutions of our country cause men to rely in a measure on their own resources, thus early developing and practising those inventive powers so peculiar to our people. We are not bound down by the local laws and prejudices of societies, as in the Old World. Here a man, if he pleases, is his own carpenter, mason, or smith. His inquiring mind and ingenuity leads him to undertake and accomplish what he desires. How little will be required to cultivate talent, and produce men who will record the history of their country in marble or imperishable bronze—in the language of nature, always to be understood. Our monuments and antiquities will not carry with them the odor of royalty and nobility, but forms of elegance and beauty.

Very respectfully, your obedient servant,

WILLIAM J. STONE.

Prof. HENRY,
Secretary Smithsonian Institution.

The Secretary exhibited a new form of meteorological blanks which he had prepared for the joint use of the Institution and the Patent Office, and also a simple form of the rain-gage, of which a number had been ordered for distribution to different parts of the country. They are so constructed as to be readily transmitted by mail.

The Secretary presented the following resolutions, which had been unanimously adopted by the Illinois State Board of Education, at a meeting held in March last:

"Whereas the Illinois State Board of Education concur in the opinion of the necessity and importance of the meteorological observations to be made, in accordance with the system established by the Smithsonian Institution, of simultaneous observations in every State of this Union; and whereas that Institution has undertaken to collect and digest all the observations which may be made on this continent; therefore,

"*Resolved,* That we will co-operate with said Institution in order to obtain full and reliable reports from the various sections of this State.

"*Resolved,* That each member of this Board select some competent and reliable person in his congressional district to take charge of the observations in said district, and from time to time report the same to the secretary of our Board.

"*Resolved*, That a committee of four be appointed by the president to memorialize the legislature for an appropriation to aid in the purchase of a set of meteorological instruments for each congressional district in our State.

"*Resolved*, That —— —— be appointed actuaries, in behalf of this Board, to collect and prepare specimens of the natural history and products of our State, and to co-operate with that department of the Smithsonian Institution."

The blank in the last resolution was filled with the names of Robt. Kennicott, of Cook county; Dr. J. Niglas, of Peoria county; and W. F. M. Arny, of McLean county.

The Secretary also presented from the author a manuscript translation of a memoir on the origin of the human race, by Baron Muller, of Marseilles, France.

He also exhibited a copy of the great work on Egypt by Lepsius, presented to the library by the Prussian government; a very expensive and valuable work on Russian antiquities, from the Imperial Library at St. Petersburg; a portfolio of colored engravings to illustrate the mosque of St. Sophia, Constantinople, from the Sultan; and other valuable donations and articles received in exchange.

The Board then adjourned, to meet at the call of the Secretary, and afterwards visited the different parts of the building.

APPENDIX.

REPORT OF THE SENATE JUDICIARY COMMITTEE.*

The following is the report presented in the Senate on the 6th February, 1855, by Judge Butler, from the Committee on the Judiciary, to whom was referred the inquiry whether any, and if any, what, action of the Senate is necessary and proper in regard to the Smithsonian Institution:

"It seems to be the object of the resolution to require the committee to say whether, in its opinion, the Regents of the Smithsonian Institution have given a fair and proper construction, within the range of discretion allowed to them, to the acts of Congress putting into operation the trust which Mr. Smithson had devolved on the federal government. As the trust has not been committed to a legal corporation subject to judicial jurisdiction and control, it must be regarded as the creature of congressional legislation. It is a naked and honorable trust, without any profitable interest in the government that has undertaken to carry out the objects of the benevolent testator. The obligations of good faith require that the bequest should be maintained in the spirit in which it was made. The acts of Congress on this subject were intended to effect this end, and the question presented is this: Have the Regents done their duty according to the requirements of the acts of Congress on the subject?

"In order to determine whether any, and if any, what, action of the Senate is necessary and proper in regard to the Smithsonian Institution, it is necessary to examine what provisions Congress have already made on the subject, and whether they have been faithfully carried into execution.

"The money with which this Institution has been founded was bequeathed to the United States by James Smithson, of London, to found at Washington, under the name of the 'Smithsonian Institution,' an establishment 'for the increase and diffusion of knowledge among men.' It is not bequeathed to the United States to be used for their own benefit and advantage only, but in trust to apply to 'the increase and diffusion of knowledge' among mankind generally, so that other men and other nations might share in its advantage as well as ourselves.

"Congress accepted the trust, and by the act of August 10, 1846, established an institution to carry into effect the intention of the testator. The language of the will left a very wide discretion in the manner of executing the trust, and different opinions might very naturally be entertained on the subject. And it is very evident by the

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* Messrs. Butler, Toucey, Bayard, Geyer Pettit, and Toombs.

law above referred to that Congress did not deem it advisable to prescribe any definite and fixed plan, and deemed it more proper to confide that duty to a Board of Regents, carefully selected, indicating only in general terms the objects to which their attention was to be directed in executing the testator's intention.

"Thus, by the fifth section, the Regents were required to cause a building to be erected of sufficient size, and with suitable rooms or halls, for the reception and arrangement, upon a liberal scale, of objects of natural history, including a geological and mineralogical cabinet; also a chemical laboratory, a library, a gallery of art, and the necessary lecture-rooms. It is evident that Congress intended by these provisions that the funds of the institution should be applied to increase knowledge in all of the branches of science mentioned in this section—in objects of natural history, in geology, in mineralogy, in chemistry, in the arts—and that lectures were to be delivered upon such topics as the Regents might deem useful in the execution of the trust. And publications by the institution were undoubtedly necessary to diffuse generally the knowledge that might be obtained; for any increase of knowledge that might thus be acquired was not to be locked up in the institution or preserved only for the use of the citizens of Washington, or persons who might visit the institution. It was by the express terms of the trust, which the United States was pledged to execute, to be diffused among men. This could be done in no other way than by publications at the expense of the Institution. Nor has Congress prescribed the sums which shall be appropriated to these different objects. It is left to the discretion and judgment of the Regents.

"The fifth section also requires a library to be formed, and the eighth section provides that the Regents shall make from the interest an appropriation, not exceeding an average of twenty-five thousand dollars annually, for the gradual formation of a library composed of valuable works pertaining to all departments of human knowledge.

"But this section cannot, by any fair construction of its language, be deemed to imply that any appropriation to that amount, or nearly so, was intended to be required. It is not a direction to the Regents to apply that sum, but a prohibition to apply more; and it leaves it to the Regents to decide what amount within the sum limited can be advantageously applied to the library, having a due regard to the other objects enumerated in the law.

"Indeed the eighth section would seem to be intended to prevent the absorbtion of the funds of the Institution in the purchase of books. And there would seem to be sound reason for giving it that construction; for such an application of the funds could hardly be regarded as a faithful execution of the trust; for the collection of an immense library at Washington would certainly not tend 'to increase or diffuse knowledge' in any other country, not even among the countrymen of the testator; very few even of the citizens of the United States would receive any benefit from it. And if the money was to be so appropriated, it would have been far better to buy the books and place them at once in the Congress library. They would be more acceptable to the public there, and it would have saved the expense of a costly building and the salaries of the officers; yet nobody would have listened to such a proposition, or consented that the United States should take to itself and for its own use the money which they accepted as a trust for 'the increase and diffusion of knowledge among men.'

"This is the construction which the Regents have given to the acts of Congress, and, in the opinion of the committee, it is the true one; and, acting under it, they have erected a commodious building, given their attention to all the branches of science mentioned in the law, to the full extent of the means afforded by the fund of the Institution, and have been forming a library of choice and valuable books, amounting already to more than fifteen thousand volumes. The books are, for the most part, precisely of the character calculated to carry out the intentions of the donor of the fund and of the act of Congress. They are chiefly composed of works published by or under the auspices of the numerous institutions of Europe which are engaged in scientific pursuits, giving an account of their respective researches and of new discoveries whenever they are made. These works are sent to the 'Smithsonian Institution,' in return for the publications of this Institution, which are transmitted to the learned societies and establishments abroad. The library thus formed, and the means by which it is accomplished, are peculiarly calculated to attain the object for which the munificent legacy was given in trust to the United States. The publication of the results of scientific researches made by the Institution is calculated to stimulate American genius, and at the same time enable it to bring before the public the fruits of its labors. And the transmission of these publications to the learned societies in Europe, and receiving in return the fruits of similar researches made by them, gives to each the benefit of the 'increase of knowledge' which either may obtain, and at the same time diffuses it throughout the civilized world. The library thus formed will contain books suitable to the present state of scientific knowledge, and will keep pace with its advance; and it is certainly far superior to a vast collection of expensive works, most of which may be found in any public library, and many of which are mere objects of curiosity or amusement, and seldom, if ever, opened by any one engaged in the pursuits of science.

"These operations appear to have been carried out by the Regents, under the immediate superintendence of Prof. Henry, with zeal, energy, and discretion, and with the strictest regard to economy in the expenditure of the funds. Nor does there seem to be any other mode which Congress could prescribe or the Regents adopt which would better fulfil the high trust which the United States have undertaken to perform. No fixed and immutable plan prescribed by law or adopted by the Regents would attain the objects of the trust. It was evidently the intention of the donor that it should be carried into execution by an institution or establishment, as it is termed in his will. Congress has created one, and given it ample powers, but directing its attention particularly to the objects enumerated in the law; and it is the duty of that Institution to avail itself of the lights of experience, and to change its plan of operations when they are convinced that a different one will better accomplish the objects of the trust. The Regents have done so, and wisely, for the reasons above stated. The committee see nothing, therefore, in their conduct which calls for any new legislation or any change in the powers now exercised by the Regents.

"For many of the views and statements in the foregoing report the committee are indebted to the full and luminous reports of the Board of Regents. From the views entertained by the committee, after an impartial examination of the proceedings referred to, the committee have adopted the language of the resolution, 'that no action of the Senate is necessary and proper in regard to the Smithsonian Institution; *and this is the unanimous opinion of the committee.*'"

LECTURES

DELIVERED AT THE SMITHSONIAN INSTITUTION.

SUBSTANCE OF A COURSE OF LECTURES ON MARINE ALGÆ

BY WILLIAM HENRY HARVEY,
OF THE UNIVERSITY OF DUBLIN.

[Professor Harvey visited this country for the purpose of studying the marine Algæ or sea-weeds of our coast. Two parts of his work have been printed by the Smithsonian Institution, and a third will appear soon after his return from his explorations on the coasts of the Pacific ocean.]

Among the plants which constitute the ordinary covering of the ground, whether that covering be one of forests, peopled by vegetable giants, or of the herbage and small herbaceous plants that clothe the open country, we observe that the greater number—at least of those which ordinarily force themselves on our notice—have certain obvious organs or parts: namely a *root* by which they are fixed in the ground, and through which they derive their nourishment from the fluids of the soil; a *stem* or axis developed, in ordinary cases, above ground; *leaves* which clothe that stem, and in which the crude food absorbed by the roots and transmitted through the stem is exposed to the influence of solar light and of the air; and, finally, special modifications of leaf buds called *flowers,* in which seeds are originated and brought to maturity. These seeds, falling from the parent plant, endowed with an independent life under whose influence they germinate, attract food from surrounding mineral matter; digest it; *organize* it, that is, convert it from dead substance into living substance; form new parts or organs from this prepared matter; and, finally, grow into vegetables, having parts similar to those of the parent plant, and similarly arranged.

This is the usual course of vegetation: seeds develop roots, stems, and leafy branches; the latter at maturity bear flowers, producing similar seeds, destined to go through a like course; and so on, from one vegetable generation to another. But, with a perfect agreement among seed-bearing plants in the end proposed and attained, there is an endless variety of minor modifications through which the end is compassed. All degrees of modification exist between the simplest and most complicated digestive organs; in some, the root, stem, and leaves are so blended together, that we lose the notion of distinct organs, and in others the leaves are reduced to scales or spines, while the stem and branches are expanded and become not merely leaf-like, but actually discharge the functions of leaves. In the reproductive organs or flowers, too, we find equal variety; from the most elaborate and often gorgeous structures to the simplest and plainest, till at last we arrive at flowers, whose organization is so low that not only have calyx and corolla disappeared, but the very seed-vessel itself is reduced to an open scale or is wholly absent. Yet in all these modifications it is merely the means that are varied; the end proposed is as efficiently attained by the simplest agency as by the most complex; as if the Creator had designed to show us plainly how it is the same to Him to act by many or by few, by the most elaborate arrangement when He wills it, and by the simplest when that is His pleasure.

In all the cases of which we have as yet spoken, *seeds* are the result of the vegetable cycle; a seed being a compound body, containing an *embryo* or miniature plant, having stem, root, and leaf already organized, and enclosed with proper coverings or seed coats. But some plants do not produce such seeds. At least one-sixth of the vegetable kingdom, perhaps more, are propagated by isolated cells (or *spores*) cast loose from the structure of which they had formed a portion, and endowed thenceforth with independent powers of growth and development. Such are the reproductive bodies of the Ferns, the Mosses, and all plants below them in the vegetable scale, concluding with the large class to which our attention will now be confined—the Algæ—which of all are the lowest and simplest in organization.

The framework of every vegetable is built up of *cells*, little membranous sacks of various forms, with walls of varying tenacity, empty, or containing fluid or granular, organized matter, from which new cells may be developed. Among more perfect plants there is, in different parts of the same individual, considerable variety in the form and substance of the cells; those of the wood and of the veins of the leaves being different from those of the soft part of the leaves, and these again different from those of the skin which is spread over the whole. But as we descend in the scale of organization, greater and greater uniformity is found. Below the *Ferns*, no vascular tissue and no proper wood-cells occur; and at last in the Algæ, no cells exist differing from those of ordinary parenchyma or soft cells, such as compose the pulp of a leaf. Algæ, then, together with Mosses, Lichens, and Fungi, are termed *cellular* plants, in contradistinction to Ferns and Flowering plants, which are denominated *vascular*. Among the most perfect of the Algæ, however, though the cells are all of the same substance and nature, all *parenchimatic*, they are of various forms and arrangement in different portions of the vegetable, often keeping up a very perfect analogy with the double system of arrangement—the vertical and horizontal, or woody and cellular systems—of higher plants. Thus the cells of the axis of the compound cylindrical Algæ are arranged longitudinally, like the wood-cells of stems, while those of the periphery or outer coating of the same Algæ have a horizontal direction.

In the most perfect of such Algæ the frame still consists of *root*, *stem*, and *leaves*, developed in an order analogous to that of higher plants. Passing from such, we meet with others gradually less and less perfect, until the whole vegetable is reduced either to a root-like body, or a branching naked stem, or an expanded leaf; as if Nature had first formed the types of the compound vegetable organs so named and exhibited them as separate vegetables; and then, by combining them in a single framework, had built up her perfect idea of a fully organized plant. But among the Algæ, we may go still lower in vegetable organization, and arrive at plants where the whole body is composed of a few cells strung together; and finally at others—the simplest of known vegetables—whose whole framework is a single *cell.* These are the true vegetable-*monads:* with these we commence the great series of the Algæ at its lowest point, and proceeding upwards we find, within the limits of this same series, all degrees of complication of framework short of the development of proper flowers. It is this progressive organization of the Algæ which renders the study of this portion of the vegetable world especially interesting to the philosophical botanist, because it displays to him, as in a mirror, something of that general plan of development which Nature has followed in constructing other and more compound plants, in which her steps are less easily traced. From its first conception within the ovule to its full development, one of the higher plants goes through transformations strictly analogous to stages of advancement that can be traced among the Algæ from species to species, and from genus to genus, from the least perfect to the most perfect of the group. Each Alga-species has its own peculiar phase of development, which it reaches, and there stops; another species, passing this condition, carries the ideal plan a step further; and thus successive species exhibit successive stages of advancement.

While their gradually advancing scale of development renders the study of these plants more interesting, it also increases the difficulty of constructing a short and yet definite character, or *diagnosis,* which will exclude every member of the group, and exclude species more properly referable to the kindred groups of LICHENS and FUNGI. I shall not here attempt any such critical definition, but proceed to trace the gradual evolution of the frond and of the organs of fructification in the Algæ, assuming that with the ALGÆ are to be classed all Thallophytes (or Cryptogamic plants destitute of proper axes, in the more restricted view of that term) which are developed in water, or nourished wholly through the medium of fluids, while all Thallophytes that are ærial and not parasitic are LICHENS, and all that are ærial and parasitic are FUNGI.

Commencing then with Algæ of the simplest structure, a large part of them, belonging to the orders *Diatomaceæ* and *Desmidiaceæ,* consist almost entirely of individual isolated cells. Each plant, or frond, is formed of a single living cell; destitute therefore of any special organs, and performing every function of life in that one universal organ of which its frame consists. The growth of these simple plants is like that of the ordinary cells of which the compound frame of higher plants is composed. Nourishment is absorbed through the membranous coating of the young plant (or cell), digested within its simple cavity, and the assimilated matter applied to the extension of the cell-wall, until that has reached the size proper to the species. Then the matter contained within the cavity gradually separates into two portions, and at the same time a cell-wall is formed between each portion, and thus the original simple cell becomes two cells. These no longer cohere together, as cells do in a compound plant, but each half-cell separates from its fellow, and commencing an independent career, digests food, increases in size, divides at maturity, &c., going again and again through a similar round of changes. In this way, by the process of self-division, and without any fructification, a large surface of water may soon be covered with these vegetable monads, from the mere multiplication of a single individual.

These minute plants, (*Diatomaceæ* and *Desmidiaceæ*) from their microscopic size and uniform and simple structure, are justly regarded as at the base of the vegetable kingdom. Notwithstanding which lowly position in the scale of being, they display an infinite variety of the most exquisite forms and finely sculptured surfaces; so that their study affords as much scope for the powers of observation as does that of the creation which is patent to our ordinary senses. These tribes are, however, omitted from this essay, because they have been made the objects of special inquiry by Professor Bailey of West Point, whose memoirs in the volumes of the Smithsonian Contributions are referred to for further information.

But *Desmidiaceæ* and *Diatomaceæ* are not the only Algæ of this simple structure. The lowest forms of the order *Palmellaceæ,* such as the *Protococcus* or *Red snow plant,* have an equally simple organization. The blood-red color of Alpine or Arctic snow which has been so often observed by voyagers, and which was seen to spread over so vast an extent of ground by Captain Ross, in his first Arctic journey, is due to more than one species of microscopic plant, and to some minute infusorial animals which perhaps acquire the red color from feeding on the *Protococcus* among which they are found. The best known and most abundant plant of this snow vegetation is the *Protococcus nivalis,* which is a spherical cell, containing a carmine-red globe of granulated, semi-fluid substance, surrounded by a hyaline limbus or thick cell-wall. At maturity the contained red matter separates into several spherical portions, each of which becomes clothed with a membranous coat; and thus forming as many small cells. The walls of the parent whose whole living substance has thus been appropriated to the offspring, now burst asunder, and the progeny escape. These rapidly increase in size until each acquires the dimensions of the parent, when the contained matter is again separated into new spheres; giving rise to new cells, to undergo in their turn the same changes. And as, under favorable circumstances, but a few hours are required for this simple growth and development, the production of the red snow plant is often very rapid: hence the accounts frequently given of the sudden appearance of a red color in the snow, over a wide space, which appearance is ascribed by common report to the falling of bloody rain or snow. In many such cases it is probable that the *Protococcus* may have existed on the portion of soil over which the snow fell, and its development may have merely kept pace with the gradually deepening sheet of snow. That this plant is not confined to the surface of snow is well known; and Captain Ross mentions that in many places where he had an opportunity of examining it, he found that it extended several feet in depth. It has been found both in Sweden and Scotland on rocks, in places remote from snow deposites; and it probably lies dormant, or slowly vegetates in such cases, waiting for a supply of snow, in which it grows with greater rapidity.

The structure and development which I have described as characterizing *Protococcus*, are strikingly similar to those of what are commonly considered minute infusorial animals, called *Volvox;* the chief difference between *Protococcus* and *Volvox* being that the latter is clothed with vibratile hairs, by the rapid motion of which the little spheres are driven in varying directions through the water. Many naturalists, and some of high note, are now of opinion that *Volvox* and its kindred should be classed with the Algæ, and certainly (as we shall afterwards see) their peculiar ciliary motion is no bar to this association. I do not pronounce on this question, because it does not immediately concern our present subject, and because, in all its collateral bearings, it requires more attentive examination than it has yet undergone.

In *Protococcus* the cell of which the plant consists is spherical or oval; in other equally elementary Algæ the cell is cylindrical, and sometimes lengthened considerably into a thread-like body. Such is the formation of *Oscillatoriæ*. In *Vaucheriæ* there is a further advance, the filiform cell becoming branched without any interruption to its cavity; and such branching cells frequently attain some inches in length, and a diameter of half a line, constituting some of the largest cells known among plants.

In all these cases each cell is a separate individual: such plants are therefore the simplest expression of the vegetable idea. But even in this extremest simplicity we find the first indication of the structure which is to be afterwards evolved. Thus in the spherical cell we have the earliest type of the cellular system of a compound plant developing equally in all directions; and in the cylindrical cell, the illustration of the vertical system developing longitudinally. These tendencies, here scarcely manifest, become at once obvious when the framework begins to be composed of more cells than one.

Thus in the genera nearest allied to *Protococcus*, the frond is a roundish mass of cells cohering irregularly by their sides. From these through *Palmella* and *Tetraspora* we arrive at *Ulva*, where a more or less compact membranous expansion is formed by the lateral cohesion of a multitude of roundish (or, by mutual pressure, polygonal) cells originating in the quadri-partition of older cells; that is, by the original cells dividing longitudinally as well as transversely, thus forming four new cells from the matter of the old cell, and causing the cell-growth to proceed nearly equally in both directions. Starting, therefore, from *Protococcus*, and tracing the development through various stages, we arrive in *Ulva* at the earliest type of an expanded leaf.

In like manner the earliest type of a stem may be found by tracing the Algæ which originate in cylindrical cells. Here the new cells are formed in a longitudinal direction only, by the bipartition of the old cells. Thus, in *Conferva*, where the body consists of a number of cylindrical cells, strung end to end, these have originated by the continual transverse division of an original cylindrical cell. Such a frond will continually lengthen, but will make no lateral growth; and consisting of a series of joints and interspaces, it correctly symbolizes the stem of one of the higher plants, formed of a succession of nodes and internodes. And the analogy is still further preserved when such confervoid threads branch; for the branches constantly originate at the joints or *nodes*, just as do the leaves and branches of the higher compound plants.

We have then two tendencies exhibited among Algæ—the first, a tendency to form membranous expansions, the symbols or types of leaves; the second, a tendency to form cylindrical bodies or stems. Among the less perfect Algæ the whole plant will consist either of one of these foliations, or of a simple or branched stem. But gradually both ideas or forms will be associated in the same individual, and exhibited in greater or less perfection. We shall find stems becoming flattened at their summits into leaves, and leaves, by the loss of their lateral membranes, and the acquisition of thicker midribs, changing into stems; and among the most highly organized Algæ we shall find leaf-like lateral branches assuming the form, and to a good degree the arrangement of the leaves of higher plants. Not that we find among Algæ proper leaves, like those of phænogamous plants, constantly developing buds in their axils; for even where leaf-like bodies are most obvious (as in the genus *Sargassum*,) they are merely *Phyllocladia* or expanded branches, as may readily be seen by observing a *Sargassum* in a young state, and watching the gradual changes that take place as the frond lengthens. These changes will be explained in the systematic portion of my work.

I shall now notice more particularly the varieties of habit observed among the compound Algæ; and first,

OF THE ROOT.

The *root* among the Algæ is rarely much developed. Among higher plants which derive their nourishment from the soil in which they grow, and in Fungi which feed on the juices of organized bodies, root-fibres, through which nourishment is absorbed, are essential to the development of the vegetable. But the Algæ do not, in a general way, derive nourishment from the soil on which they grow. We find them growing indifferently on rocks of various mineralogical character, on floating timber, on shells, on iron or other metal, on each other—in fine, on any substance which is long submerged, and which affords a foothold. Into none of those substances do they emit roots, nor do we find that they cause the decay, or appropriate to themselves the constituents, of those substances. They are nourished by the water that surrounds them and the various substances which are dissolved in it. On those substances they frequently exert a very remarkable power, effecting chemical changes which the chemist can imitate only by the agency of the most powerful apparatus. They actually sometimes reverse the order of chemical affinity, driving out the stronger acid from the salts which they imbibe, and causing a weaker acid to unite with the base. Thus they decompose the muriate of soda which they absorb from sea-water, partly freeing and partly appropriating the chlorine and hydrogen; and the soda is found combined in their tissues with carbonic acid.

A remarkable instance of the action of a minute Alga on a chemical solution was pointed out to me by Prof. Bache, as occurring in the vessels of sulphate of copper kept in the electrotyping department of the Coast Survey office at Washington. A slender confervoid Alga infests the vats containing sulphate of copper, and proves very destructive. It decomposes the salt, and assimilates the sulphuric acid, rejecting (as indigestible !) the copper, which is deposited round its threads in a metallic form. It sometimes appears in great quantities, and is very troublesome; but the vats had been cleaned a few days before I visited them, so that I lost the opportunity of examining more minutely this curious little plant. Most probably it is a species of *Hygrocrocis*,* a group of Algæ of low organization but strong digestive powers, developed in various chemical solutions or in the waters of mineral springs. All the Algæ, however, which are found in such localities are not species of *Hygrocrocis*, for several *Oscillatoriæ* and *Calothrices* occur in thermal waters. Species of the former genus are found even in the boiling waters of the Icelandic Geysers. Of the latter, one species at least, *Calothrix nivea*, is very common in hot sulphur springs, and I observed it in great plenty in the streams running from the inflammable springs at Niagara.

But on whatever substance the Alga may feed, it is rarely obtained through the intervention of a root. Dissolved in the water that bathes the whole frond, the food is imbibed equally through all the cells of the surface, and passes from cell to cell towards those parts that are more actively assimilating, or growing more rapidly. The *root*, where such an organ exists, is a mere holdfast, intended to keep the plant fixed to a base, and prevent its being driven about by the action of the waves. It is ordinarily a simple disc, or conical expansion of the base of the stem, strongly applied and firmly adhering to the substance on which the Alga grows. This is the usual form among all the smaller growing kinds. Where, however, as in the gigantic Oar-weeds or *Laminariæ*, the frond attains a large size, offering a proportionate resistance to the waves, the central disc is strengthened by lateral holdfasts or discs formed at the bases of side roots emitted by the lower part of the stem; just as the tropical Screw-pine (*Pandanus*) puts out cables and shrouds to enable its slender stem to support the weight of the growing head of branches. The branching roots of the *Laminaria*, then, are merely *Fucus*-discs become compound: instead of the conical base of a *Fucus*, formed of a single disc, there is a conical base formed of a number of such discs disposed in a circle. In some few instances, as in *Macrocystis*, the grasping fibres of the root develop more extensively, and form a matted stratum of considerable extent, from which many stems spring

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* Perhaps the *Hygrocrocis cuprica*, Kütz, or some allied species; but I had no opportunity of examining a recent specimen, and the characters cannot be made out from a dried one.

up. This is a further modification of the same idea, a further extension of the base of the cone.

In all these cases the roots extend over flat surfaces, to which they adhere by a series of discs. They show no tendency to penetrate like the branching roots of perfect plants. The only instances of such penetrating roots among the Algæ with which I am acquainted, occur in certain genera of *Siphoneæ* and in the *Caulerpeæ*, tropical and subtropical forms, of which there are numerous examples on the shores of the Florida Keys. These plants grow either on sandy shores or among coral, into which their widely extended fibrous roots often penetrate for a considerable distance, branching in all directions, and forming a compact cushion in the sand, reminding one strongly of the much divided roots of sea-shore grasses that bind together the loose sands of our dunes. But neither in these cases do the roots appear to differ from the nature of holdfasts, and their ramification and extension through the sand is probably owing to the unstable nature of such a soil. It is not in search of nourishment, but in search of stability, that the fibres of their roots are put forth, like so many tendrils. We shall have more to speak of these roots in the proper place, and shall now proceed to notice some of the forms exhibited by—

THE FROND.

The *frond* or vegetable body of the compound Algæ puts on a great variety of shapes in different families, as it gradually rises from simpler to more complex structures. In the less organized it consists of a string of cells arranged like the beads of a necklace; and the cells of which such strings are composed may be either globose or cylindrical. In the former case we have a *moniliform* string or *filament*, and in the latter a filiform or cylindrical one. The term *filament* (in Latin, *filum*) is commonly applied to such simple strings of cells, but has occasionally a wider acceptation, signifying any very slender, threadlike body, though formed of more than one series of cells. This is a loose application of the term, and ought to be avoided. By Kützing the term *trichoma* is substituted for the older word *filum* or filament. Where the *filament* (or *trichoma*) consists of a single series of consecutive cells, it appears like a jointed thread; each individual cell constituting an *articulation*, and the walls between the cells forming *dissepiments* or *nodes*, terms which are frequently employed in describing plants of this structure. Where the filament is composed of more series of cells than one, it may be either *articulated* or *inarticulate*. In the former case, the cells or articulations of the minor filaments which compose the common filament are all of equal length; their dissepiments are therefore all on a level, and divide the compound body into a series of nodes and internodes, or dissepiments and articulations. In the latter, the cells of the minor filaments are of unequal length, so that no articulations are obvious in the compound body. In *Polysiphonia* and *Rhodomela* may be seen examples of such articulate and inarticulate filaments.

By Kützing the term *phycoma* is applied to such compound stems;

and when the phycoma becomes flattened or leaf-like, a new term, *phylloma*, is given to it by the same author. These terms are sometimes convenient in describing particular structures, though not yet generally adopted. The cells of which compound stems (or *phycomata*) are composed are very variously arranged, and on this cellular arrangement, or internal structure of the stem, depends frequently the place in the system to which the plant is to be referred. A close examination, therefore, of the interior of the frond, by means of thin slices under high powers of the microscope, is often necessary, before we can ascertain the position of an individual plant whose relations we wish to learn. Sometimes all the cells have a longitudinal direction, their longer axes being vertical. Very frequently, this longitudinal arrangement is found only towards the centre of the stem, while towards the circumference the cells stand at right angles to those of the centre, or have a horizontal direction. In such stems we distinguish a proper *axis*, running through the frond, and a *periphery*, or *peripheric stratum*, forming the outside layer or circumference. Sometimes the axis is the densest portion of the frond, the filaments of which it is composed being very strongly and closely glued together; in other cases it is very lax, each individual filament lying apart from its fellow, the interspaces being filled up with vegetable mucus or gelatine. This gelatine differs greatly in consistence; in some Algæ it is very thin and watery, in others it is slimy, and in others it has nearly the firmness of cartilage. On the degree of its compactness and abundance depends the relative *substance* of the plant; which is membranaceous where the gelatine is in small quantity; gelatinous where it is very abundant and somewhat fluid; or cartilaginous where it is firm.

The frond may be either cylindrical or stem-like, or more or less compressed and flattened. Often a cylindrical stem bears branches which widen upwards, and terminate in leaf-like expansions, which are of various degrees of perfection in different kinds. Thus sometimes the leaf, or *phylloma*, is a mere dilatation; in other cases it is traversed by a midrib, and in the most perfect kinds lateral nervelets issue from the midrib and extend to the margin. These leaves are either vertical, which is their normal condition, or else they are inclined at various angles to the stem or axis, chiefly from a twisting in their lamina, the insertion of the leaf preserving its vertical position. They are variously lobed or cloven, and in a few cases (as in the *Sea Colander* of the American coast) they are regularly pierced, at all ages, with a series of holes which seem to originate in some portions of the lamina developing new cells with greater rapidity than other parts, thus causing an unequal tension in various portions of the frond, and consequently the production of holes in those places where the growth is defective. Such plants, though they form lace-like fronds, are scarcely to be considered as net-works. Net-like fronds are, however, formed by several Algæ where the branches regularly anastomose one with another, and form meshes like those of a net. Most species with this structure are peculiar to the Southern Ocean, but in the waters of the Caribbean Sea are found two or three which may perhaps yet be detected on the shores of the Florida Keys. In one of the Australian genera of this structure (*Claudea*) the net-work is formed by the continual anastomosis of minute leaflets, each of which is furnished with a midrib and lamina. The apices of the midribs of one series of these leaves grow into the dorsal portion of leaves that issue at right angles to them, and as the leaves having longitudinal and horizontal directions, or those that form the warp and weft of the frond, are of minute size and closely and regularly disposed, the net-work that results is lace-like and delicately beautiful.

In the *Hydrodictyon*, a fresh-water Alga, found in ponds in Europe and in the United States, where it was first detected by Professor Bailey near West Point, a net-like frond is formed in a different manner. This plant when fully grown resembles an ordinary fishing-net of fairy size, each pentagonal mesh being formed of five cells, and one cell making a side of the pentagon. As the plant grows larger, the meshes become wider by the lengthening of the cells of which each mesh is composed. When at maturity, the matter contained within each cell of the mesh is gradually organized into granules, or germs of future cells, and these become connected together in fives while yet contained in the parent cell. Thus meshes first, and at length little microscopic net-works, are formed within each cell of the meshes of the old net; and this takes place before the old net breaks up. At length the cells of the old net burst, and from each issues forth the little net-work, perfectly formed, but of very minute size, which, by an expansion of its several parts, will become a net like that from which its parent cell was derived. Thus, supposing each cell of a single net of the Hydrodictyon were to be equally fertile, some myriads of new nets would be produced from every single net as it broke up and dissolved. In this way a large surface of water might be filled with the plant in a single generation.

The manner of growth of the frond is very various in the different families. In some, the body lengthens by continual additions to its apex, every branch being younger the further removed it is from the base; that is, the tips of the branches are the youngest parts. This is the usual mode of growth in the Confervoid genera, and also obtains in many of those higher in the series, as in the Fucaceæ and many other Melanosperms. In the Laminariæ, on the contrary, the apex, when once formed, does not materially lengthen, but the new growth takes place at the base of the lamina, or in the part where the cylindrical stipe passes into the expanded or leaflike portion of the frond. In such plants the apex is rarely found entire in old specimens, but is either torn by the action of the waves or thrown off altogether, and its place supplied by a new growth from below. In several species this throwing off of the old frond takes place regularly at the close of each season; the old lamina being gradually pushed off by a young lamina growing under it. There are others, among the filiform kinds, in which the smaller branches are suddenly deciduous, falling off from the larger and permanent portions of the trunk, as leaves do in autumn from deciduous trees. Hence specimens of these plants collected in winter are so unlike the summer state of the species, that to a person unacquainted with their habits they would appear to be altogether different in kind. The summer and winter states of

Rhodomela subfusca are thus different. In *Desmarestia aculeata* the young plants, or the younger branches of old plants, are clothed with soft pencils of delicate jointed filaments, which fall off when the frond attains maturity, and leave naked, thorny branches behind. Similar delicate hairs are found in many other Algæ of very different families, generally clothing the younger and growing parts of the frond ; and they seem to be essential organs, probably engaged in elaborating the crude sap of these plants, and consequently analogous to the leaves of perfect plants. This is as yet chiefly conjectural. The conjecture, however, is founded on the observed position of these hair-like bodies, which are always found on growing points, the new growth taking place immediately beneath their insertion. In most cases these hairs are deciduous ; but in some, as in the genus *Dasya*, they are persistent, clothing all parts of the frond so long as they continue in vigor. They vary much in form, in some being long, filiform, single cells ; in others, unbranched strings of shorter cells, and in others dichotomous, or, rarely, pinnated filaments.

Three principal varieties of

COLOR

are generally noticed among the Algæ, namely, *Grass-green* or *Herbaceous*, *Olive-green*, and *Red;* and as these classes of color are pretty constant among otherwise allied species, they afford a ready character by which, at a glance, these plants may be separated into natural divisions ; and hence *color* is here employed in classification with more success than among any other vegetables. In the subdivision of Algæ into the three groups of *Chlorosperms*, *Melanosperms*, and *Rhodosperms*, the color of the frond is, as we shall afterwards see, employed as a convenient diagnostic character. It is a character, however, which must be cautiously applied in practice by the student, because, though sufficiently constant on the whole and under ordinary circumstances, exceptions occur now and then ; and under special circumstances Algæ of one series assume in some degree the color of either of the other series.

The *green* color is characteristic of those that grow either in fresh water or in the shallower parts of the sea, where they are exposed to full sunshine but seldom quite uncovered by water. Almost all the fresh-water species are green, and perhaps three fourths of those that grow in sunlit parts of the sea ; but some of those of deep water are of as vivid a green as any found near the surface, so that we cannot assert that the *green* color is owing here, as it is among land plants, to a perfect exposure to sunlight. Several species of *Caulerpa*, *Anadyomene*, *Codium*, *Bryopsis* and others of the Siphoneæ, which are not less herbaceous or vivid in their green colors than other Chlorosperms, frequently occur at considerable depths, to which the light must be very imperfectly transmitted.

Algæ of an *olivaceous* color are most abundant between tide-marks, in places where they are exposed to the air, at the recess of the tide, and thus alternately subjected to be left to parch in the sun, and to be flooded by the cool waves of the returning tide. They extend, however, to low-water mark, and form a broad belt of vegetation about that level, and a few straggle into deeper water, sometimes into very deep water. The gigantic deep-water Algæ, *Macrocystis*, *Nereocystis*, *Lessonia*, and *Durvillœa*, are olive-colored.

Red-colored Algæ are most abundant in the deeper and darker parts of the sea, rarely growing in tide pools, except where they are shaded from the direct beams of the sun either by a projecting rock, or by over-lying olivaceous Algæ. The red color is always purest and most intense when the plant grows in deep water, as may be seen by tracing any particular species from the greatest to the least depth at which it is found. Thus, the common *Ceramium rubrum* in deep pools or near low-water mark is of a deep, full red, its cells abundantly filled with bright carmine endochrome, which will be discharged in fresh water so as to form a rose-colored infusion; but the same plant, growing in open, shallow pools, near high-water mark, where it is exposed to the sun, becomes very pale, the color fading through all shades of pink down to dull orange or straw-color. It is observable that this plant, which is properly one of the *red* series (or Rhodosperms,) does not become grass-green (or like a Chlorosperm) by being developed in the shallower water, but merely loses its capacity for forming the red-colored matter peculiar to itself. So, also, *Laurencia pinnatifida*, and other species of that genus, which are normally dark purple, are so only when they grow near low-water mark. And as many of them extend into shallower parts, and some even nearly to high-water limit, we find specimens of these plants of every shade of color from dull purple to dilute yellow or dirty white. Similar changes of color, and from a similar cause, are seen in *Chondrus crispus*, the *Carrigeen* or *Irish Moss*, which is properly of a fine deep purplish red, but becomes greenish or whitish when growing in shallow pools. The *white* color, therefore, which is preferred in carrigeen by the purchaser of the prepared article, is entirely due to bleaching and repeated rinsing in fresh water.

Many Algæ, both of the *olive* and *red* series, and in a less perfect manner a few of the *grass-green* also, reflect prismatic colors when growing under water. In some species of *Cystoseira*, particularly in the European *C. ericoides* and its allies, these colors are so vivid that the dull olive-brown branches appear, as they wave to and fro in the water, to be clothed with the richest metallic greens and blues, changing with every movement, as the beams of light fall in new directions on them. Similar colors, but in a less degree, are seen on *Chondrus crispus* when growing in deep water; but here the prismatic coloring is often confined to the mere tips of the branches, which glitter like sapphires or emeralds among the dark purple leaves. The cause of these changeable colors has not been particularly sought after. The surface may be finely striated, but it does not seem to be more so than in other allied species, where no such iridescence has been observed. In the *Chondrus* the changeable tints appear to characterize those specimens only which grow in deep water, and which are stronger and more cartilaginous than those which grow in shallow pools.

Fresh water has generally a very strong action on the colors as well as on the substance of marine Algæ which are plunged into it.

To many it is a strong poison, rapidly dissolving the gelatine which connects the cells, and dissolving also the walls of the cells themselves; and that so quickly that in a few minutes one of these delicate plants will be dissolved into a shapeless mass of broken cells and slime. Many species which, when fresh from the sea, resist the action of fresh water, and may be steeped in it without injury for several hours, if again moistened after having once been dried, will almost instantly dissolve and decompose. This is remarkably the case with several species of *Gigartina* and *Iridæa*. The first effect of fresh water on the red colors of Algæ is to render them brighter and more clear. Thus *Dasya coccinea, Gelidium cartilagineum, Plocamium coccineum*, and others, are when recent of a very dark and somewhat dull red color; but when exposed either to showers and sunshine on the beach, or to fresh-water baths in the studio of the botanist, become of various tints of crimson or scarlet, according as the process is continued for a less or greater length of time. At length the coloring matter would be expelled and the fronds bleached white, as occurs among the specimens cast up and exposed to the long continued action of the air; but if stopped in time and duly regulated, the colors may be greatly heightened by fresh water. Some plants which are dull brown when going into the press, come out a fine crimson; this is the case with *Delesseria sanguinea*, though that plant is not always of a dull color when recent. Others, which are of the most delicate rosy hues when recent, become brown or even black when dried. This is especially the case in the order *Rhodomelaceæ*, so named from this tendency of their reds to change to black in drying. The tendency to become black, though it cannot be altogether overcome in these plants, may often be lessened by steeping them in fresh water for some time previous to drying. Hot water generally changes the colors of all Algæ to green, and if heat be applied during the drying process, an artificial green may be imparted to the specimens; but such a mode of preparation of specimens ought never to be practised by botanical collectors, though it may sometimes serve the purpose of makers of seaweed pictures.

THE FRUCTIFICATION

of the Algæ will be more fully described in the systematic portion of my work, when speaking of the various forms it assumes in the different families. I shall at present, therefore, limit myself to a very few general observations. The *spore* or reproductive gemmule of the Algæ is in all cases a simple cell, filled with denser and darker colored endochrome (or coloring matter) than that found in other cells of the frond. In the simplest Algæ, where the whole body consists of a single cell, some gradually change and are converted into spores, without any obvious contact with others: but far more frequently, as in the *Desmidiaceæ* and *Diatomaceæ*, a spore is formed only by the conjugation of two cells or individual plants. When these simple vegetable atoms are mature, and about to form their fructification, two individuals are observed to approach; a portion of the cell-wall of each is then extended into a tubercle at opposite points; these tubercles come into contact, and at length become confluent; the dissepiment between them vanishes, and a tube is thus formed connecting the two cavities together. Through this tube the matter contained in both the old cells is transmitted and becomes mixed; changes take place in its organization, and at length a *sporangium,* or new cell filled with spores is formed from it, either in one of the old cells, or commonly at the point of the connecting tube, where the two are soldered together. Then the old empty cells or plants die, and the species is represented by its *sporangium*, which may remain dormant, retaining vitality for a considerable time, as from one year to another, or probably for several years. These sporangia, which are abundantly formed at the close of the season of active growth, become buried in the mud at the bottoms of pools, where they are encased on the drying up of the water in summer, and are ready to develop into new fronds on the return of moisture in spring.

Many of the lower Algæ form fruit in this manner, to which the name *conjugation* is technically given. The thread-like Silk-weeds of ponds and ditches (*Zygnemata* and *Mougeotiæ,* &c.,) are good examples of such a mode of fruiting. In these almost every cell is fertile, and when two threads are yoked together, a series of *sporangia* will be formed in one thread, while the other will be converted into a string of dead, empty cells. Before conjugation there was, seemingly, no difference between the contents of one set of cells and of the other; so that there is no clear proof of the existence of distinct sexes in these plants, however much the process of fruiting observed among them may indicate an approach to it.

The process of fruiting in the higher Algæ appears to be very similar: namely, *spores* or *sporangia* appear to be formed by certain cells attracting to themselves the contents of adjacent cells; and in the compound kinds, empty cells are almost always found in the neighborhood of the fruit cells; but with the complication of the parts of the frond, the exact mode in which spores are formed becomes more difficult of observation. At length, among the highest Algæ we encounter what appear to be really two sexes, one analogous to the anther, and the other to the pistil of flowering plants. It would seem, however, that it is not each individual spore which is fertilized, as is the case in seed-bearing plants; but that the fertilizing influence is imparted to the pistil or sporangium itself, when that body is in its most elementary form, long before any spore is produced in its substance, and even when it is itself scarcely to be distinguished from an ordinary cell. *Antheridia,* as the supposed fertilizing organs are called, are most readily seen among the *Fucaceæ,* and will be described under that family.

Besides the reproduction by means of proper spores, many Algæ have a second mode of continuing the species, and some even a third. Among the simpler kinds, where the whole body consists of a single cell, a fissiparous division, exactly similar to the fissiparous multiplication of cells among higher plants, takes place. This cell, as has been already mentioned, divides at maturity into two parts, which, falling asunder, become separate individuals. Similar self-division has been noticed among the lower *Palmellaceæ*, and in other imperfectly organized families. Such a mode of multiplying individuals is analogous to the propagation of larger plants by the process of gemmation, where buds are formed and thrown off to become new individuals. When, as in the *Lemna* or *Duckweed*, the whole vegetable body is as simple as a phanerogamous plant can well be, the new frondlets or buds are produced in a manner very strikingly analogous to the production of new fronds in *Desmidiaceæ*.

The third mode of continuing the species has been observed in many Algæ of the *green* series, in some of which sporangia are also formed, but in others no fructification other than what I am about to describe has been detected. This mode is as follows. In an early stage, the green matter, or *endochrome*, contained within the cells of these Algæ, is of a nearly homogeneous consistence throughout, and semi-fluid; but at an advanced period it becomes more and more granulated. The granules when formed in the cells at first adhere to the inner surface of the membranous wall, but soon detach themselves and float freely in the cell. At first they are of irregular shapes, but they gradually become spheroidal. They then congregate into a dense mass in the centre of the cell, and a movement aptly compared to that of the swarming of bees round their queen begins to take place. One by one these active granules detach themselves from the swarm, and move about in the vacant space of the cell with great vivacity. Continually pushing against the sides of the cell wall, they at length pierce it, and issue from their prison into the surrounding fluid, where their seemingly spontaneous movements are continued for some time. These vivacious granules, or *zoospores*, as they have been called, at length become fixed to some submerged object, where they soon begin to develop cells, and at length grow into Algæ similar to those from whose cells they issued.

Their spontaneous movements before and immediately subsequent to emission lead me to speak of the

MOVEMENTS OF ALGÆ

in general. These are of various kinds, and of greater or less degrees of vivacity. In some Algæ a movement from place to place continues through the life of the individual, while in others, as in the zoospores of which I have just spoken, it is confined to a short period, often to a few hours, in the transition state of the spore, after it escapes from the parent filament, and until it fixes itself and germinates. Many observers have recorded these observations, which are to be found detailed in various periodicals.* I shall here notice only a few cases illustrative of the various kinds of movement. The most ordinary of these movements is effected by means of vibratile *cilia* or hairs, produced by the membrane of the spore, and which, by rapid backward and forward motion, like that of so many microscopic oars, propel the body through the water in different directions, according as the move-

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* See *Annales des Sciences Naturelles; Taylor's Ann. Nat. Hist.;* the *Linnæa, &c.*, various volumes.

ment is most directed to one side or the other. Sometimes the little spores, under the influence of these cilia, are seen to spin round and round in widening circles; but at other times change of direction, pauses, accelerations, &c., take place during the voyage, which look almost like *voluntary* alterations, or as if the spore were guided by a principle of the nature of animal will. Hence many observers do not hesitate to call these moving spores *animalcules*, and to consider them of the same nature as the simpler infusorial animals.

This, as it appears to me, is a conclusion which ought not to be hastily assumed, not merely taking into consideration the extremely minute size of the little bodies to be examined, and the consequent danger of our being deceived as to the cause of movement, and of its interruption and resumption, but also remembering the facts ascertained by Mr. Brown, of the movement of small particles of all mineral substances which he examined. Many of the spores in question are sufficiently small to come under the Brownian law, though others are of larger size. Besides, if we regard the moving spores as animalcules, we must either adopt the paradox that a vegetable produces an animal, which is then changed into a vegetable, and the process repeated through successive generations, every one of these *vegetables* having been *animal* in its infancy; or else, notwithstanding their strongly-marked vegetable characteristics, we must remove to the animal kingdom all Algæ with moving spores.

Neither of these violent measures is necessary, if we admit that mere motion, apart from other characters, is no *proof* of animality. Though motion under the control of a will be indeed one of the charter privileges of the higher animals, we see it gradually reduced as we descend in the animal scale, until at last it is nearly lost altogether. Long before we reach the lowest circles in the animal world, we meet with animals which are fixed through the greater part of their lives to the rocks on which they grow, and some of them have scarcely any obvious movement on their point of attachment. In some the surface, like that of the Algæ spores, is clothed with cilia, which drive floating particles of food within reach of the mouth; in others, even these rudimentary prehensile organs are dispensed with, and the animal exists as a scarcely irritable flesh expanded on a framework. This would seem to be the case in the corals of the genus *Fungia*, if the accounts given of those animals be correct; while in the sponges the animal structure and organization are still further reduced, so as almost to contravene our preconceived notions of animal will and movement. But the sponges can scarcely be far removed from Fungia, nor can that be separated from other corals; so that, though I am aware some naturalists of eminence regard the sponges as vegetables, I cannot subscribe to that opinion, but rather view them as exhibiting to us animal organization in its lowest conceivable type, and parallel to vegetable organization, as that exists in the lowest members of the class of Algæ.

This hasty glance at the animal kingdom teaches us that voluntary motion is a character variable in degree, and at length reduced almost to zero within the animal circle. On the other hand, we know that movements of a very extraordinary character exist among the higher vegetables. Not merely the movement of the fluids of plants within their cells, which has at least some analogy with the motion of animal fluids; but in such plants as the Sensitive plant, the Venus's Flytrap, (*Dionæa*,) and many others, movements of the *limbs* (shall I call them?) as singular as those of the Algæ spores, are sufficiently well known. And these movements are affected by narcotics in a manner strikingly similar to the operation of similar agents on the nervous system of animals. The common sensitive plant, indeed, only shrinks from the touch, but in the *Desmodium gyrans*, a movement of the leaves on their petioles is habitually kept up, as if the plant were fanning itself continually. Such vegetable movements as these strike us by their rapidity, but others of a like nature only escape us by their slowness. Thus, the opening of the leaves of many plants in sunlight, and their closing regularly in the evening in sleep; the constant turning of the growing points towards the strongest light, and other changes in position of various organs, are all vegetable movements, which would appear as *voluntary* as those of the Algæ spores, if they were equally rapid. Their extreme slowness alone conceals their true nature.

So, then, we find animals in which *motion* is reduced almost to a nullity, and vegetables as high in the scale as the *Leguminosæ*, exhibiting well-marked movements—facts which sufficiently establish the truth of our position, that *mere motion* is no proof of animality. But subtracting their movements from the Algæ spores, what other proof remains of their being animalcules? None whatever. They do not resemble animalcules, either in their internal structure, their chemical composition, or their manner of feeding; and their vegetable nature is sufficiently marked by their decomposing carbonic acid, giving out oxygen in sunlight, and containing starch.

In the *Vaucheria clavata*, one of the species in which spores moved by cilia were first observed, the spore is formed at the apices of the branches. The frond in this plant is a cylindrical, branching cell, filled with a dense, green endochrome. A portion of the contained endochrome immediately at the tips separates from that which fills the remainder of the branch; a dissepiment is formed, and that portion cut off from the rest gradually consolidates into a spore, while the membranous tube enlarges to admit of its growth. The young spore soon becomes elliptical, and at length, being clothed with a skin and ready for emission, it escapes through an opening then formed at the summit of the branch. The whole surface of the spore, when emitted, is seen to be clothed with vibratile cilia, whose vibrations propel it through the water until it reaches a place suitable for germination. The cilia then disappear, and the spore becoming quiescent, at length develops into a branching cell like its parent. The history of other moving spores is very similar, the cilia, however, varying much in number in different species. Commonly there are only two, which are sometimes inserted as a pair, at one end of the spore, but in other cases placed one at each end.

There are other Algæ in which vibratile cilia have not been observed, but which yet have very agile movements. Among these the most remarkable are the *Oscillatoriæ* and their allies, which suddenly appear and diappear in the waters of lakes and ponds, and sometimes rise to the surface in such prodigious numbers as to color it for many square miles. In *Oscillatoria* each individual is a slender, rigid, needle-shaped thread, formed of a single cell, filled with a dense endochrome which is annulated at short intervals, and which eventually separates into lenticular spores. Myriads of such threads congregate in masses, connected together by slimy matter, in which they lie, and from the borders of which, as it floats like a scum on the water, they radiate. Each thread, loosely fixed at one end in the slimy matrix, moves slowly from side to side, describing short arcs in the water, with a motion resembling that of a pendulum; and, gradually becoming detached from the matrix, it is propelled forward. These threads are continually emitted by the stratum, and diffused in the water, thus rapidly coloring large surfaces. When a small portion of the matrix is placed over night in a vessel of water, it will frequently be found in the morning that filaments emitted from the mass have formed a pellicle over the whole surface of the water, and that the outer ones have pushed themselves up the sides, as far as the moisture reaches.

The Oscillatoriæ, though most common in fresh water, are not peculiar to it. Some are found in the sea, and others in boiling springs, impregnated with mineral substances. It has been ascertained that the red color which gives name to the Arabian Gulf is due to the presence of a microscopic Alga (*Trichodesmium erythræum*,) allied to Oscillatoria, and endowed with similar motive powers, which occasionally permeates the surface-strata of the water in such multitudes as completely to redden the sea for many miles. The same or a similar species has been noticed in the Pacific Ocean in various places, by almost every circumnavigator since the time of Cook, who tells us his sailors gave the little plant the name of "sea sawdust." Mr. Darwin compares it to minute fragments of chopped hay, each fragment consisting of a bundle of threads adhering together by their sides.

These minute plants move freely through the water, rising or sinking at intervals, and when closely examined they exhibit motions very similar to those of *Oscillatoriæ*. There are several of such quasi-animal-plants now known to botanists, and almost all belong to the *green* series of the Algæ, which are placed in our system at the extreme base of the vegetable scale of being.

HABITAT.

The *habitat* or place of growth of the Algæ is extremely various. Wherever moisture of any kind lies long exposed to the air, Algæ of one group or other are found in it. I have already alluded to the *Hygrocrocis*, so troublesome in vats of sulphate of copper, and many, perhaps almost all other chemical solutions, become filled in time, and under favorable circumstances, with a similar vegetation. The waters of mineral springs, both hot and cold, have species peculiar to them. Some, like the Red snow plant, diffuse life through the otherwise barren snows of high mountain peaks and of the polar regions; and on the surface of the polar ice an unfrozen vegetation of minute Algæ finds an appropriate soil. There are species thus fitted to endure all observed varieties of temperature. Moisture and air are the only essentials to the development of Algæ. It has even been supposed that the minute *Diatomaceæ* whose bodies float through the higher regions of the atmosphere, and fall as an impalpable dust on the rigging of ships far out at sea, have been actually developed in the air; fed on the moisture semicondensed in clouds; and carried about with these "lonely" wanderers.

When this atmospheric dust was first noticed, naturalists conjectured that the fragments of minute Algæ of which the microscope showed it to be composed, had been carried up by ascending currents of air either from the surface of pools, or from the dried bottoms of what had been shallow lakes. But a different origin has recently been attributed to this precipitate of the atmosphere by Dr. F. Cohn, Professor Ehrenberg, and others, who now regard it as evidence of the existence of organic life in the air itself! This opinion is founded on the alleged fact, that atmospheric dust, collected in all latitudes, from the equator to the circumpolar regions, consists of remains of the same species, and that certain characteristic forms are always found in it, and are rarely seen in any other place. Hence it is inferred that the dust has a common origin, and its universal diffusion round the earth points to the air itself as the proper abode of this singular fauna and flora—for minute animals would seem to accompany and doubtless to feed upon the vegetable atoms. If this be correct, and not an erroneous inference from a misunderstood phenomenon, it is one of the most extraordinary facts connected with the distribution and maintenance of organic life.

If Algæ thus people the finely divided vapor that floats above our heads, we shall be prepared to find them in all water condensed on the earth. The species found on damp ground are numerous. These are usually of the families *Palmellaceæ* and *Nostochaceæ*. To the latter belong the masses of semi-transparent green jelly so often seen among fallen leaves on damp garden walks, after continued rains in autumn and early winter. These jellies are popularly believed to fall from the atmosphere, and by our forefathers were called *fallen stars*.* If such be their origin, we are tempted to address them, with Cornwall in King Lear:

> "Out, vile jelly! where is thy lustre now?"

for certainly nothing can well be less star-like than a Nostoc, as it lies on the ground.

An appeal to the microscope reveals beauty indeed in this humble plant, but gives no countenance to the popular belief of its meteoric descent. It is closely related in structure to other species found under dripping rocks and in lakes and ponds, and the only reason for regarding it as an aerial visitant is the suddenness of its appearance after rain.

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* Other substances besides Nostocs occasionally get this name. Masses of undeveloped frog-spawn, for instance, dropped by buzzards and herons, pass for meteoric deposits.

In certain moist states of the atmosphere, accompanied by a warm temperature, the Nostoc grows very rapidly; but what seems a *sudden* production of the plant has possibly been long in preparation unobserved. When the air is dry the growth is intermitted, and the plant shrivels up to a thin skin; but on the return of moisture this skin expands, becomes gelatinous, and continues its active life. And as this process is repeated from time to time, it may be that the large jelly which is found after a few days' rain is of no very recent growth. A friend of mine who happened to land in a warm dry day on the coast of Australia, and immediately ascended a hill for the purpose of obtaining a view of the country, was overtaken by heavy rains; and was much surprised to find that the whole face of the hill quickly became covered with a gelatinous Alga, of which no traces had been seen on his ascent. In descending the hill in the afternoon, on his return to the ship, he was obliged to slide down through the slimy coating of jelly, where it was impossible to proceed in any other way. No doubt, in this case, a species of *Nostoc* which had been unnoticed when shrivelled up had merely expanded with the morning's rain.

Where water lies long on the surface of the ground, as happens in cases of floods, it quickly becomes filled with *Confervæ* or *Silk-weeds*, which rise to the surface in vast green strata. These simple plants grow with great rapidity, using up the materials of the decaying vegetation which is rotting under the inundation, and thus they in great measure counteract the ill effects to the atmosphere of such decay. When the water evaporates, their filaments, which consist of delicate membranous cells, shrivel up and become dry, and the stratum of threads, now no longer green, but bleached into a dull white, forms a coarsely interwoven film of varying thickness, spread like great sheets of paper over the decaying herbage. This *natural paper*, which has also been described under the name of *water flannel*, sometimes covers immense tracts, limited only by the extent of the flood in whose waters it originated.

But though Algæ abound in all reservoirs of fresh water, the waters of the sea are their peculiar home; whence the common name "Sea-weeds," by which the whole class is frequently designated. Very few other plants vegetate in the sea, sea-water being fatal to the life of most seeds; yet some notable exceptions to this law (in the case of the cocoanut, mangrove, and a few other plants) serve a useful purpose in the economy of nature.

The sea in all explored latitudes has a vegetation of Algæ. Towards the poles, this is restricted to microscopic kinds, but almost as soon as the coast rock ceases to be coated with ice, it begins to be clothed with *Fuci*, and this without reference to the mineral constituents of the rock, the Fucus requiring merely a resting place. Sea-weeds rarely grow on sand, unless when it is very compact and firm. There are, therefore, submerged sandy deserts, as barren as the most cheerless of the African wastes. And when such barrens interpose, along a considerable extent of coast, between one rocky shore and another, they oppose a strong barrier to the dispersion of species, though certainly not so strong as the aerial deserts; because the waters which flow over submarine sands will carry the spores of the Algæ with less injury than the winds of the desert will convey the seeds of plants from one oasis to another. It cannot, however, be doubted that submerged sands do exercise a very material influence on the dispersion of Algæ, or their

GEOGRAPHICAL DISTRIBUTION.

Climate has an effect on the Algæ as upon all other organic bodies, though its influence is less perceptible in them than in terrestrial plants, because the temperature of the sea is much less variable than that of the air. Still, as the temperature of the ocean varies with the latitude, we find in the marine vegetation a corresponding change, certain groups, as the *Laminariæ*, being confined to the colder regions of the sea; and others, as the *Sargassa*, only vegetating where the mean temperature is considerable.

These differences of temperature and corresponding changes of marine vegetation, which are mainly dependent on actual distance from the equatorial regions, are considerably varied by the action of the great currents which traverse the ocean, carrying the waters of the polar zone towards the equator, and again conveying those of the torrid zone into the higher latitudes. Thus, under the influence of the warm waters of the Gulf Stream, Sargassum is found along the east coast of America as far as Long Island sound (lat. 44°.) And again, the cold south-polar current which strikes on the western shores of South America, and runs along the coasts of Chili and Peru, has a marked influence on the marine vegetation of that coast, where *Lessonia*, *Macrocystis*, *Durvillæa*, and *Iridæa*, characteristic forms of the marine flora of Antarctic lands, approach the equator more nearly than in any other part of the world.

The influence of currents of warmer water is also observable in the submarine flora of the west coast of Ireland, where we find many Algæ abounding in lat. 53°, which elsewhere in the British Islands are found only in the extreme south points of Devon and Cornwall. These, and other instances which might be given, are sufficient to show that average temperature has a marked influence in determining the marine vegetation of any particular coast.

Seasons of greater cold or heat than ordinary have, as might be inferred, a corresponding action. This is particularly noticeable among the smaller and more delicate kinds which grow within tide marks, and are found in greater luxuriance or in more abundant fruit in a warm than in a cold season. And the difference becomes more strongly marked when the particular species is growing near the northern limit of its vegetation. Thus in warm summers, *Padina Pavonia* attains, on the south coast of England, a size as large as it does in sub-tropical latitudes; while in a cold season it is dwarf and stunted.

In speaking of the difference in color of Algæ, I have already noticed the prevalence of particular colors at different depths of water. A corresponding change of specific form takes place from high to low water mark; and as the depth increases, the change is strikingly analogous to what occurs among land plants at different elevations above the sea. Depth in the one case has a correspondent effect to height in the other;

and the Algæ of deep parts of the sea are to those of tidal rocks, as alpine plants are to littoral ones. In both cases there is a limit to the growth of species; each aerial species having a line above which it does not vegetate, and each marine one a line beyond which it does not descend. And as, at last, we find none but the least perfect lichens clothing the rocks of high mountains, so in the sea beyond a moderate depth are found no Algæ of higher organization than the *Diatomaceæ*. These latter atomic plants would appear to exist in countless numbers at very extraordinary depths, having been constantly brought up by the lead in the deep-sea soundings recorded in Sir James Ross's Antarctic voyage. But ordinary sea plants cease to vegetate in comparatively shallow water, long before animal life ceases. The limits have not been accurately ascertained, and are probably much exaggerated as commonly given in books.

Lamouroux speaks of ordinary Algæ growing at 100 to 200 fathoms, but we have no exact evidence of the existence of these plants at this great depth. The *Macrocystis*, the largest Alga known, has sometimes been seen vegetating in 40 fathoms (*Hook. Fl. Ant. vol.* 2, *p.* 464) water, while its stems not merely reached the surface, but rose at an angle of 45° from the bottom, and streamed along the waves for a distance certainly equal to several times the length of the "Erebus;" data which, if correct, give the total length of stem at about 700 feet. Dr. Hooker, however, considers this an exceptional case, and gives from eight to ten fathoms as the utmost depth at which submerged seaweed vegetates in the southern temperate and Antarctic ocean; a depth which is probably much exceeded in the tropics, and which is at least equalled by Algæ of the north temperate zone.

Humboldt, in his "Personal Narrative," mentions having dredged a plant to which he gave the name *Fucus vitifolius*, (probably a *Codium* or *Flabellaria*) in water 32 fathoms deep, and remarks that, notwithstanding the weakening of the light at that depth, the color was of as vivid a green as in Algæ growing near the surface. I possess a specimen of *Anadyomene stellata* dredged at the depth of 20 fathoms, in the Gulf of Mexico, by my venerable friend the late Mr. Archibald Menzies, and it is as green as specimens of the same plant collected by me between tide marks at Key West, and is much more luxuriant.

Professor Edward Forbes, whose admirable report on the Ægean Sea should be consulted by all persons interested in the distribution of life at various depths, dredged *Constantinea reniformis*, Post. and Rupr. in 50 fathoms, the greatest depth perhaps on record, as accurately observed, at which ordinary Algæ vegetate. I say, ordinary Algæ, for it will be remembered that Diatomaceæ exist in the profound abysses of the ocean, as far as we are acquainted with them.

And besides these microscopic vegetables, Algæ of a group called *Nullipores* or *Corallines* (*Corallinaceæ*), long confounded with the Zoophytes, become more numerous as other Algæ diminish, until they characterize a zone of depth where they form the whole obvious vegetation. These remarkable plants assimilate the muriate of lime of seawater and form a carbonate in their tissues, which from the great abundance of this deposit become stony. The less perfect Nullipores are scarcely distinguishable, by the naked eye, from any ordinary calcareous incrustation, and strongly resemble the efflorescent forms, like cauliflowers, seen so frequently in the sparry concretions of limestone caverns. Others, more perfect, become branched like corals; and the most organized of the group, or the true corallines, have symmetrical, articulated fronds. This stony vegetation affords suitable food to hosts of zoophytes and mollusca, which require lime for the construction of their skeletons or shells, and it probably extends to a depth as great as such animals inhabit.

When the same species is found at different depths, there is generally a marked difference between the specimens. Thus, when an individual plant grows either in shallower or in deeper water than that natural to the species, it becomes stunted or otherwise distorted. I have noticed in many species (as in *Plocamium coccineum*, *Dasya coccinea*, *Laurencia dasyphylla*, various *Hypneæ*, and many others) that the specimens from deep water have divaricated branches and ramuli, and a tendency to form both hooks and discs or supplementary roots, from various points of the stem and branches. Sometimes the outward habit is so completely changed by the production of hooked processes and discs, that it is difficult to discover the affinity of these distorted forms; and such specimens have occasionally been unduly elevated to the rank of species.

When water of great depth intervenes, on a coast between two shallower parts of the sea, it frequently limits the distribution of species, acting as a high mountain range would in the distribution of land plants, but in a far less degree; as it is obviously easier for the spores of the Algæ to be floated across the deep gulf, than for the seeds of land plants to pass the snowy peaks of a mountain.

The intervention of sand, already alluded to, is a far greater barrier, because sandy tracts are usually of much greater extent than submarine obstacles of any other kind. To the prevalence of a sandy coast, in a great measure probably, is owing the very limited distribution of the *Fucaceæ* on the eastern shores of North America, where plants of this family are scarcely found from New York to Florida. Since the erection of a breakwater at Sullivan's Island, S. C., many Algæ not before known in those waters have, according to Professor L. R. Gibbes's authority, made their appearance, but none of the Fucaceæ are yet among them. In due time *Sargassum vulgare* will probably arrive from the south.

Some attempt has been made to divide the marine flora into separate regions, the particulars of which I have detailed elsewhere.* In the descriptive portion of my work I shall notice the distribution of the several families, where it offers any marked peculiarity, and I shall at present confine myself to some remarks on the distribution of Algæ along the eastern and southern shores of the United States; here recording the substance of some verbal observations which I made at the Meeting of the American Association, held in Charleston, in March, 1850.

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* *Manual of British Marine Algæ*, *Introd.*, p. xxxvi et seq. ed. 2.

EASTERN SHORES OF NORTH AMERICA.

In comparing the marine vegetation of the opposite shores of the northern Atlantic, a great resemblance is observed between the ordinary seaweeds that clothe the rocks on the eastern and western sides; with this difference, that the species do not reach so high a latitude on the American shore as on the European. The reason of this will be readily understood by inspecting a physical map of the Atlantic, on which Humboldt's isothermal lines, or lines of mean annual temperature, are laid down. For then it will at once be seen that there is a very considerable bending of the isothermal lines in favor of the continent of Europe. Thus the same line that runs through New York, in lat. 41°, strikes the shores of Europe in the north of Ireland, lat. 54°. And though there is less difference in mean temperature in the southern parts of the continents than in the northern, still there is a marked difference throughout.

With respect to vegetation, *Laminaria longicruris* is common on the American shore—at least as far south as Cape Cod (lat. 42°); while on the European it has not been found south of Norway, save some stray, waterworn stems occasionally cast on the north of Ireland or Scotland.

Rodymenia crystata, so very abundant in Boston harbor, (42° 30′) where it enters largely into the composition of *seaweed pictures*, is rarely found in Europe south of Iceland and the northern parts of Norway; its most southern limit being in the Frith of Forth, (56°), where it has been found but once or twice.

Delesseria hypoglossum has not been observed in America north of Charleston, (lat. 33°), while in Europe it occurs in Orkney, (lat. 59°), and is in great profusion and luxuriance on the north coast of Ireland in lat. 55°. The distribution of this species on the American shore is very anomalous if Charleston be its northern limit, for it certainly extends southward at least to Anastasia Island, (lat. 29° 50′). In the British seas it is most luxuriant on the Antrim shore, (55°), where its fronds are sometimes three feet in length; southern specimens are generally much smaller, and in Devonshire it rarely measures more than three or four inches, which is the average size of specimens from the south of Europe, as well as of those found in Charleston harbor. If we are correct in limiting the American distribution of this species northward by Charleston, we have the remarkable fact that the greatest latitude attained by *Del. hypoglossum* in the northwestern Atlantic is less by about 5° or 6° than the *southern* limit of the same species on the northeastern, and by about 27° than the northern boundary of its distribution. This indicates a range which the isothermal lines can scarcely explain; for the line which runs through Charleston strikes the coast of Spain. It is the more remarkable in this species, because the genus *Delesseria* is most numerous in the colder parts of the sea, its finest species being natives of Northern Europe and of Cape Horn and the Falkland Islands; and, as we have seen, this very *D. hypoglossum* is nowhere of greater size or in greater plenty than in latitude 55° on the Irish coast.

It is different with *Padina Pavonia*, itself a tropical form, and belonging to a group peculiarly lovers of the sun. We are not surprised that in America this plant should not grow further north than the Keys of Florida, although, under some peculiarly favorable circumstances, it attains a limit 27° further north, on the south coast of England; for in the land-vegetation of the two coasts there is something like an approach to similar circumstances, *oranges* and *citrons* being occasionally ripened in the open air in Devonshire, and *Magnolia grandiflora* attaining an arborescent size. The remaining marine vegetation of the Florida Keys, as we shall presently see, has a greater resemblance to that of the Mediterranean than to that of the British coasts; and this is more in accordance with the land floras, in which palm trees are a feature in both countries.

Probably one-half the species of Algæ of the east coast of North America are identical with those of Europe—a very large portion when we contrast it with the strongly marked difference between the marine animals of the two shores; the testacea, and to a great extent even the fishes of the two continents, being dissimilar. The European species, on the same length of coast, are greatly the more numerous, which appears to be owing to the prevalence of sands, nearly destitute of Algæ, along so great a length of the American shore, and particularly along that portion which, from its latitude, ought to produce the greatest variety of Algæ, were the local circumstances favorable to their growth.

As Algæ are little indebted for nourishment to the soil on which they grow, merely requiring a secure resting place and a sheltered situation, their number generally bears a proportion to the amount of indented rocks that border the coast. Stratified rocks are more favorable to their growth than loose boulders or stones; but if the upper surface be smooth without cavities, it is either swept by the waves too rapidly to allow the growth of a vigorous vegetation; or, in quiet places, it becomes uniformly clothed with some of the Fuci, or other *social* species, which cover the exposed surface with a large number of individuals, to the destruction of more delicate species. The rocks, then, most adapted for Algæ are those in which, here and there, occur deep cavities affording shelter from the too boisterous waves. In these, on the recess of the tide, a *tide pool* or rock basin preserves the delicate fronds from the action of the sun. The rare occurrence of such situations on the American coast is doubtless a reason of the comparative poverty of the marine flora.

This comparative poverty is observable even in the common littoral Fuci or Rock Kelp. In Northern Europe, besides several rarer kinds, six species (namely *Fucus serratus*, *vesiculosus*, *nodosus*, *canaliculatus*; *Halidrys siliquosa*; and *Himanthalia lorea*) are extremely common, four of them at least being found on every coast. In America, *Fucus vesiculosus* and *nodosus* alone are commonly dispersed; *F. serratus* and *canaliculatus* have not yet been detected; and the *Halidrys* and *Himanthalia* rest on very uncertain evidence: so that of the *six* common European kinds, only *two* are certainly found in America. This deficiency in *Fucaceæ* is, in degree, made up for in *Laminariaceæ*, of which family several are peculiar to the American shore, the most remarkable of which is the *Agarum* or Sea Colander.

Among the red Algæ (or *Rhodosperms*), species with expanded, leaf-like fronds are proportionably less numerous than on the European side. *Delesseria sanguinea* is absent on the American shore, where its place is supplied by *D. Americana*, a species of equally brilliant coloring, but lower in organization, connecting *Delesseria* with *Nytophyllum.* This latter genus, of which there are so many fine European species, is scarcely known in North America. A few scraps of *Nytophylla* (almost too imperfect to describe), picked up at the mouth of the Wilmington river, N. C., and at Key West, are all the evidence we at present possess of the existence of that type of form on the North American shore. *Plocamium coccineum*, so abundant in Europe, and which is also widely dispersed in the Southern ocean, extending from Cape Horn eastward to New Zealand, has not, that I am aware of, been found on the American Atlantic coast, where its place seems taken by the equally brilliant *Rhodymenia cristata. Ceramium rubrum* is as common on the American as on the European coast, and many of the other common American *Rhodosperms* are natives of both continents.

The Green Algæ (*Chlorosperms*) are still more alike; but several of the American Cladophoræ (not yet fully explored) seem to be peculiar. *Codium tomentosum,* which is common to the shores of Europe from Gibraltar, in lat. 36°, to Orkney in lat. 60°, and perhaps further north, has yet been found only on the Florida Keys, (lat. 24°). Judging from its distribution in other parts of the world, particularly in the Pacific and Southern Oceans, one would have expected to find it all along the East coast of North America.

Perhaps it would be premature to indicate regions of Algæ into which the Eastern and Southern shores of the North American States may be divided, a few points only having as yet been carefully explored. Halifax harbor, Massachusetts Bay, Long Island Sound at several points from Greenport to New York, New York harbor, and the neighborhood of Charleston, S. C., are the chief points at which the materials for my essay have been collected on the East coast. Our knowledge of southern Algæ is at present derived chiefly from a partial examination of the Florida Keys, by Dr. Wurdemann, Professor Tuomey, Dr. Blodgett and myself. I think it probable, however, that future researches will indicate four regions of distribution, as follows:

1st. COAST NORTH OF CAPE COD, EXTENDING PROBABLY TO GREENLAND. Among the characteristic forms of this region are the great Laminariæ, particularly *L. Longicruris*, one of the largest Algæ on the coast, and *Agarum Turneri* and *pertusum.* Several of the rarer Fucaceæ seem also to be confined to this district. One of the most abundant and characteristic species of this tract is *Rhodymenia cristata*, which has not to my knowledge been found farther south than Cape Cod. Specimens said to have come from Staten Island have been shown to me, but the evidence on which the habitat of these rests is not satisfactory, and none of the Brooklyn and New York Algologists (a numerous and indefatigable band) have yet detected the plant in their harbor.

Ptilota plumosa is also a plant of this region, the only species (as far as I know) that is met with in Long Island Sound being *P. sericea*, Gm. *Rhodomelæ* are more abundant here than in the Sound, but are not limited to this division; *Odonthalia* (a peculiarly nothern form) has been seen only at Halifax. *Dumontia ramentacea*, so abundant at Iceland, is found also at Newfoundland, and near Halifax, where I gathered it plentifully. Of this plant I possess a single specimen, picked up by Miss Frothingham on Rye Beach, New Hampshire. All the species I have mentioned are Arctic forms confined in the European waters to very high latitudes, and all appear to vegetate nearly as far south as Cape Cod, to which limits they are almost all confined. The Marine flora of this region as a whole bears a resemblance to that of the shores of Iceland, Norway, Scotland, and the North and North West of Ireland.

2d. LONG ISLAND SOUND, including under this head New York harbor and the sands of New Jersey.

The natural limit of this region on the south is probably Cape Hatteras, but after passing New York the almost unbroken line of sand is nearly destitute of Algæ. I have not received any collection of sea plants made between Long Branch and Wilmington. In comparing the plants of the sound with those of our 1st region, a very marked difference is at once seen. We lose the Arctic forms, *Agarum*, *Rhod. cristata*, *Odonthalia*, *Dumontia ramentacea*, and *Ptilota plumosa*, whose place is supplied by *Sargassum*, of which genus two species are found at Greenport and at other points in the Sound; by various beautiful *Callithamnia* and *Polysiphoniæ;* and by abundance of *Delesseria Americana* and *Dasya elegans.* Those two latter plants are not limited to this region, but are greatly more abundant here than north of Cape Cod. *Del. Americana* seems almost to carpet the harbor of Greenport, and is equally abundant in various points in the Sound, and *Dasya elegans* grows to an enormous size in New York harbor, and is plentiful throughout the region. *Seirospora Griffithsiana* is not uncommon; it grows luxuriantly at New Bedford, whence Dr. Roche has sent me many beautiful specimens of it, and of other *Ceramieæ. Rhabdonia Baileyi*, *Gracilaria multipartita*, (narrow varieties) *Chrysymenia divaricata* and *C. Rosea* are also characteristic forms. *Delesseria Leprieurii*, found in the Hudson at West Point, scarcely belongs to this region, but is a tropical form at its utmost limit of northern distribution.

3d. CAPE HATTERAS TO CAPE FLORIDA. Of the Algæ characterizing this region we know little except those found in the neighborhood of Charleston, and a few specimens collected at Wilmington, N. C., and at Anastasia Island. Many species found within these limits are common to the second region; others are here met with for the first time. Of these the most remarkable are *Arthrocladia villosa* and a *Nitophyllum*, found at Wilmington; a noble *Grateloupia*, probably new (*G. Gibbesii*, MS.) found at Sullivan's Island, and *Delesseria hypoglossum*, already mentioned as occurring at Charleston and Anastasia Island. I have seen no Fucoid plant from this region; but if there were a suitable locality, we ought here to have *Sargassa.* None grow at Sullivan's Island, where *Grateloupia Gibbesii* is the largest sea plant, and the one most resembling a Fucus. All the æstuaries of this district produce *Delesseria Leprieurii*, and a *Bostrychia*, either *B. radicans*, Mont., or a closely allied species. These last are tropical forms first noticed on the shores of Cayenne, where the former was found both on maritime rocks, and on the culms of grasses in the æstuary of the Sinnamar river. With us these plants grow on the palmetto logs in Charleston harbor, and on *Spartina glabra* as far up the river as the water continues sensibly salt. *Del. Leprieurii* was collected by Dr. Hooker at New Zealand, accompanied by a *Bostrychia*. No other habitats for it are known.

4th. Florida Keys, and Shores of the Mexican Gulf. Here we have a very strongly marked province, strikingly contrasting in vegetation with the East Coast, comprised in the three regions already noticed. As yet the Keys have been very imperfectly explored, and we are almost unacquained with the marine vegetation of the main land of Florida, Alabama, Louisiana, and Texas. Of 130 species which I collected at Key West in February, 1850, scarcely one-eighth are common to the East Coast, seven-eighths being unknown on the American shore to the north of Cape Florida. With this remarkable difference between the Algæ of the Keys and those of the East Coast, there is a marked affinity between the former and those of the South of Europe. The marine vegetation of the Gulf of Mexico has a very strong resemblance to that of the Mediterranean Sea. Nearly one-third of the species which I collected are common to the Mediterranean. Several of them straggle northwards along the coast of Spain and France, and even reach the south of England; but scarcely any of these are seen on the East coast of America. We may hence infer that they are not conveyed by the gulf-stream. My collection at Key West included 10 Melanosperms, 5 of which are common to the Mediterranean; 82 Rhodosperms, 25 of which are Mediterranean; and 38 Chlorosperms, of which 10 are Mediterranean. Besides these identical species, there are many *representative* species closely allied to Mediterranean types. This resemblance is clearly shown in the genus *Dasya*, of which *seven* out of *eleven* European species are found in the Mediterranean. At Key West I collected eight species of this beautiful genus. Among these, seven were new, and the eighth (*D. elegans*) is found along the whole Eastern coast of North America. Three-fourths, perhaps, of the masses of seaweed cast ashore at Key West belong to *Laurencia*, of which genus several species and innumerable puzzling varieties are profusely common. A fine *Hypnea* (*H. Wurdemanni*, MS.) one of the most striking species of the genus, is also abundant. *Alsidium triangulare*, *Digenia simplex*, *Acanthophora*, *Amansia multifida*, and other common West Indian Rhodosperms, are abundantly cast ashore. *Sargassum vulgare* and *bacciferum*, *Padina Pavonia*, *Zonaria lobata*, and sundry *Dictyotæ*, are characteristic Melanosperms. But this region is chiefly remarkable for the abundance and beauty of its *Chlorosperms* of the groups *Siphonaceæ* and *Caulerpaceæ*. Ten species of *Caulerpa* were collected, some of which are of common occurrence, and serve for food to the turtles, which, in their turn are the staple article of diet of the islanders. *Penicillus* (at least three species), *Udotea*, *Halimeda*, *Acetabularia*, *Anadyomene*, *Dictyo-*

sphæria, *Chamædoris*, *Dasycladus*, *Cymopolia*, and others, some of which are West Indian, some Mediterranean, are evidence of the high temperature of the sea round the Keys. Many of the plants obtained by me at Key West were cast up from deeper water when the south wind blew strongly, and were not seen at any other time. A visitor, therefore, in the *hurricane months*, would probably obtain many which escaped me. Among the new species two *Delesseriæ*, (D. *involvens*, and *D. tenuifolia*) both bolonging to the hypophyllous section, are specially worth notice. These were very plentiful in the beginning of February, but soon disappeared. Two *Bostrychiæ* (*B. Montagnei*, and *B. filicula*, MS.) and a *Catenella* were found on the stems of mangroves near high-water mark; but it would extend this notice to too great a length, were I to enumerate all the forms which occur in this prolific region.

COLLECTING AND PRESERVING SPECIMENS.

I shall here give, for the convenience of the student, the substance of some directions for collecting and preserving specimens, issued by the Director of the Dublin University Museum.

Marine Algæ, as has already been stated, are found from the extreme of high-water mark to the depth of from thirty to fifty fathoms; which latter depth is perhaps the limit in temperate latitudes; the majority of *deep-water* species growing at five to ten fathoms. Those within the limits of the tidal influence are to be sought at low water, especially the lowest water of spring tides; for many of the rarer and more interesting kinds are found only at the verge of low-water mark, either along the margin of rocks partially laid bare, or, more frequently, fringing the deep tide-pools left at low water on a flattish rocky shore. The northern or shaded face of the tide-pool will be found richest in *red* algæ, and the most sunny side in those of an *olive* or *green* color. Algæ which grow at a depth greater than the tide exposes, are to be sought either by dredging, or by dragging after a boat an iron cross armed with hooks, on all shores where those contrivances can be applied; but where the nature of the bottom, or the difficulty of procuring boats, renders dredging impossible, the collector must seek for deep-water species among the heaps of sea-wrack thrown up by the waves. After storms seaweed sometimes forms enormous banks along the coast; but even in ordinary tides many delicate species, dislodged by the waves, float ashore, and may be picked up on the beach in a perfect state. The rocky portions of a coast should, therefore, be inspected at low water; and the sandy or shingly beach visited on the return of the tide. In selecting from heaps we should take those specimens only that have suffered least in color or texture by exposure to the air; rejecting all bleached or half melted pieces.

Collectors should carry with them one or two strong glass bottles with wide mouths, or a hand-basket lined with japanned tin or gutta percha, for the purpose of bringing home in *sea-water* the smaller and more delicate kinds. This precaution is often absolutely necessary, for many of the *red* algæ rapidly decompose if exposed, even for a short time, to the air, or if allowed to become massed together with plants of coarser texture. The cooler such delicate species are kept the better; and too many ought not to be crowded together in the same bottle, as crowding encourages decomposition; and when this has begun, it spreads with fearful rapidity. These Algæ should be kept in sea-water until they can be arranged for drying, and the more rapidly they are prepared the better. Many will not keep, even in vessels of sea-water, from one day to another.

A common botanist's vasculum, or an India-rubber cloth bag, will serve to bring home the larger and less membranous or gelatinous kinds; but even these, if left long unsorted, become clotted together, and suffer proportionably.

In gathering Algæ from their native places, the *whole* plant should be plucked from the very base, and if there be an obvious root, it should be left attached. Young collectors are apt to pluck branches or mere scraps of the larger Algæ, which often afford no just notion of the mode of growth or natural habit of the plant from which they have been snatched, and are often insufficient for the first purpose of a *specimen*, that of ascertaining the plant to which it belongs. In many of the leafy Fucoid plants, (*Sargassa*, &c.) the leaves that grow on the lower and on the upper branches are quite different, and were a lower and an upper branch plucked from the same root, they might be so dissimilar as to pass for portions of different species. It is very necessary, therefore, to gather, when it can be done, *the whole plant, including the root.* It is quite true that the large kinds may be judiciously divided; but the young collector had better aim at selecting moderately sized specimens of the entire plant, than attempt the division of large specimens, unless he keep in view this maxim: every botanical specimen should be an epitome of the essential marks of a species.

Several duplicate specimens of every kind should always be preserved, and particularly where the species is a variable one. Very many Algæ vary in the comparative breadth of the leaves, and in the degree of branching of the stems; and when such varieties are noticed, a considerable series of specimens is often requisite to connect a broad and a narrow form of the same species. A neglect of this care leads to endless mistakes in the after work of identification of species, and has been the cause of burdening our systems with a troublesome number of synonymes.

Where it is the collector's object to preserve Algæ in the least troublesome manner, and in a rough state, to be afterwards laid out and prepared for pressing at leisure, the specimens fresh from the sea are to be spread out and left to dry in an airy, but not too sunny, situation. They are not to be washed or rinsed in fresh water, nor is their natural moisture to be squeezed from them. The more loosely and thinly they are spread out the better, and in dry weather they will be sufficiently dry after a few hours' exposure to allow of packing. In a damp state of the atmosphere the drying process will occupy some days. No other preparation is needed, and they may be *loosely* packed in paper bags or boxes, a ticket of the exact locality being affixed to each parcel. Such specimens will shrink very considerably in drying, and most will have changed color more or less, and the bundle have become very unsightly; nevertheless, if thoroughly dried, to prevent mouldiness or heating, and packed *loosely*, such specimens will continue for a long time in a perfectly sound state; and on being re-moistened and properly pressed, will make excellent cabinet specimens.

It is very much better, when drying Algæ in this rough manner, *not* to wash them in fresh water, because the salt they contain serves to keep them in a pliable state, and causes them to imbibe water more readily on re-immersion. All large and coarse growing Algæ may be put up in this manner, and afterwards, at leisure, prepared for the herbarium by washing, steeping, pressing, and drying between folds of soft paper, in the same way that land plants are pressed and dried. But with the membranous and gelatinous kinds, a different method must be adopted.

The smaller and more delicate Algæ must be prepared for the herbarium as soon as practicable after being brought from the shore. The mode of preparation is as follows, and, after a few trials and with a little care, will soon be learned.

The collector should be provided with three flat dishes or large deep plates, and one or two shallower plates. One of the deep plates is to be filled with sea-water, and the other two with fresh water. In the dish of sea-water the stock of specimens to be laid out may be kept. A specimen taken from the stock is then introduced into one of the plates of fresh water, washed to get rid of dirt or parasites that may infest it, and pruned or divided into several pieces, if the branches be too dense, or the plant too tufted, to allow the branches to lie apart when the specimen is displayed on paper. The washed and pruned specimens are then floated in the second dish until a considerable number are ready for laying down. They are then removed separately into one of the shallower plates, that must be kept filled with *clean* water; in which they are floated and made to expand fully. Next, a piece of white paper of suitable size is carefully introduced under the expanded specimen. The paper then, with the specimen remaining displayed upon it, is cautiously brought to the surface of the water, and gently and carefully drawn out, so as not to disarrange the branches. A forceps, a porcupine's quill, a knitting needle, or an etching tool, or any finely pointed instrument will assist the operator in displaying the branches and keeping them separate while the plant is lifted from the water; and should any branch become matted in the removal, a little water dropped from a spoon over the tangled portion, and the help of the finely pointed tool, will restore it.

The piece of wet paper with the specimen upon it is to be laid on a sheet of soft soaking paper, and others laid by its side until the sheet is covered. A piece of thin calico or muslin, as large as the sheet of soaking paper, is then spread over the wet specimens. More soaking paper, and another set of specimens covered with cotton, are laid on these; and so a bundle is gradually raised. This bundle, consisting of sheets of specimens, is then placed between flat boards, under moderate pressure, and left for some hours. It must then be examined, the specimens on their white papers must be placed on dry sheets of soaking paper, covered with fresh cloths, and again placed under pressure. And this process must be repeated every day until the specimens are fully dry.

In drying, most specimens will be found to adhere to the papers on which they have been displayed, and care must be taken to prevent their sticking to the pieces of cotton cloth laid over them. Should it be found difficult to remove them from the muslin, it is better to allow them to dry, trusting to after-removal, than to tear them away in a half-dried state, which would probably destroy the specimens. A few dozen pieces of unglazed thin cotton cloth of proper size should always be at hand, (white muslin, that costs six or eight cents per yard, answers very well). These cloths will be required only in the first two or three changes, for when the specimen has begun to dry on the white paper it will not adhere to the soaking paper laid over it. In warm weather the smaller kinds will often be found perfectly dry after forty-eight hours' pressure, and one or two changes of papers.

USES OF THE ALGÆ.

The uses of the Algæ may be considered under two points of view, namely, the general office which this great class of plants, as a class, discharges in the economy of nature; and those minor useful applications of separate species which man selects on discovering that they can yield materials to supply his various wants.

The part committed to the Algæ in the household of nature, though humble when we regard them as the lowest organic members in that great family, is not only highly important to the general welfare of the organic world, but, indeed, indispensable. This we shall at once admit, when we reflect on the vast preponderance of the ocean over the land on the surface of the earth, and bear in mind that almost the whole submarine vegetation consists of Algæ. The number of species of marine plants which are not Algæ proper is extremely small. These on the American coast are limited to less than half a dozen, only one of which, the common *Eel Grass* (*Zostera marina*,) is extensively dispersed.

All other marine plants are referable to Algæ; the wide-spread sea would therefore be nearly destitute of vegetable life were it not for their existence. Almost every shore—where shifting sands do not forbid their growth—is now clothed with a varied band of Algæ of the larger kinds; and microscopic species of these vegetables (*Diatomaceæ*) teem in countless myriads at depths of the ocean as great as the plummet has yet sounded, and where no other vegetable life exists. It is not, therefore, speaking too broadly to say that the sea, in every climate and at all known depths, is tenanted by these vegetables under one phase or other.

The sea, too, teems with animal life—that "great and wide sea, wherein are things creeping innumerable, both small and great beasts," affords scope to hordes of animals, from the "Leviathan" whale to the microscopic polype, transparent as the water in which he swims, and only seen by the light of the phosphoric gleam which he emits. Now this exuberant animal creation could not be maintained without a vegetable substructure. It is one of the laws of nature that animals shall feed on organized matter, and vegetables on unorganized. For the support of animal life, therefore, we require vegetables to change the mineral constituents of the surrounding media into suitable nutriment.

In the sea this office of vegetation is almost exclusively committed to the Algæ, and we may judge of the completeness with which they execute their mission by the fecundity of the animal world which depends upon them. Not that I would assert that all, or nearly all, the marine animals are directly dependent on the Algæ for their food; for the reverse is notoriously the case. But in every class we find species which derive the whole or a part of their nourishment from the Algæ, and there are myriads of the lower in organization which do depend upon them altogether.

Among the higher orders of Algæ feeders I may mention the Turtles, whose *green fat*, so prized by aldermanic palate, may possibly be colored by the unctuous green juices of the *Caulerpæ* on which they browse. But without further notice of those that directly depend on the Algæ, it is manifest that all must ultimately, though indirectly, depend on whatever agency in the first instance seizes on inorganic matter, and converts it into living substance suitable to enter into the composition of animal nerve and muscle; and this agency is assuredly the office of the vegetable kingdom, here confined in the main to Algæ. We thus sufficiently establish our position that the Algæ are indispensable to the continuance of organic life in the sea.

As being the first vegetables that prey upon dead matter, and as affording directly or indirectly a pasture to all water animals, the Algæ are entitled to notice. Yet this is but one-half of the task committed to them. Equally important is the influence which their growth exerts on the water and on the air. The well-known fact that plants, whilst they fix carbon in an organized form in extending their bodies by the growth of cells, exhale oxygen gas in a free state, is true of the Algæ as of other vegetables. By this action they tend to keep pure the water in which they vegetate, and yield also a considerable portion of oxygen gas to the atmosphere. I have already stated that whenever land becomes flooded, or wherever an extensive surface of shallow water—whether fresh or salt—is exposed to the air, *Confervæ* and allied Algæ quickly multiply. Every pool, every stagnant ditch is soon filled with their green silken threads. These threads cannot grow without emitting oxygen. If you examine such a pool on a sunny day, you may trace the beads of oxygen on the submerged threads, or see the gas collect in bubbles where the threads present a dense mass. It is continually passing off into the air while the Confervæ vegetate, and this vegetation usually continues vigorous, one species succeeding another as it dies out, as long as the pool remains. And when, on the drying up of the land, the Confervæ die, their bodies, which are scarcely more than membranous skins filled with fluid, shrivel up, and are either carried away by the wind or form a papery film over the exposed surface of the ground. In neither case do they breed noxious airs by their decomposition. All their life long they have conferred a positive benefit on the atmosphere, and at their death they at least do no injury. The amount of benefit derived from each individual is indeed minute, but the aggregate is vast when we take into account the many extensive surfaces of water dispersed over the world, which are thus kept pure and made subservient to a healthy state of the atmosphere. It is not only vast, but it is worthy of Him who has appointed to even the meanest of His creatures something to do for the good of His creation.

These general uses of the Algæ, apparent as they are on a slight reflection, are apt to be overlooked by the utilitarian querist, who will see no use in anything which does not directly minister to his own wants, and who often judges of the use of a material by the dollars and cents which it brings to his pocket.

It would be in vain to adduce to him the indirect benefit derived to the rest of creation through the lower animals which the Algæ supply with food; for probably he would turn round with the further demand, "What is the *use* of feeding all these animals?" And he might think, too, that the amount of oxygen in the air was quite enough to last out at least his time, without such constant renovation as the Algæ afford, or that sufficient renovation would come from other sources had the Algæ never been created. "Show me," he would say, "how I can make money of them, and then I will admit the *uses* of these vegetables." This I shall therefore now endeavor to do, by summing up a few of the uses to which Algæ have been applied by man.

Man, in his least cultivated state, seeks from the vegetable kingdom, in the first place, a supply for the cravings of hunger, and afterwards medicine or articles of clothing. As *food*, several species of Algæ are used both by savage and civilized man, but more frequently as condiments than as staple articles of consumption. Many kinds commonly found on the shores of Europe are eaten by the peasantry. The midrib of *Alaria esculenta*, stripped of the membranous wings, is eaten by the coast population of the north of Ireland and Scotland; but to less extent than the dried fronds of *Rhodymenia palmata*, the *Dulse* of the Scotch, and *Dillisk* of the Irish. This latter species varies considerably in texture and taste, according to the situation in which it grows. When it grows parasitically on the stems of the larger *Laminariæ* it is much tougher and less sweet, and therefore less esteemed than when it grows among mussels and Balani near low-water mark. It is this latter variety which, under the name of "shell dillisk," is most prized. In some places on the west of Ireland this plant forms the chief relish to his potatoes that the coast peasant enjoys; but its use is by no means confined to the extreme poor. It is eaten occasionally, either from pleasure or from an opinion of its wholesomeness, by individuals of all ranks, but, except among the poor, the taste for it is chiefly confined to children. It is commonly exposed for sale at fruit stalls in the towns of Ireland, and may be seen in similar places in the Irish quarters of New York. In the Mediterranean it forms a common ingredient in soups; but notwithstanding M. Soyer's attempt in the famine years to teach this use of it to the Irish, they have not yet learned to prefer it cooked. Occasionally, however, it is fried.

Chondrus crispus, the *Carrageen* or *Irish Moss* of the shops, is dissolved, after long boiling, into a nearly colorless insipid jelly, which may then be seasoned and rendered tolerably palatable. It is considered a nourishing article of diet, especially for invalids, and has been recommended in consumptive cases. At one time, before it was generally known to be a very common plant on rocky coasts, it fetched a considerable price in the market. Though called "Irish moss," it is abundant on all the shores of Europe and of the northern States of America. It is, perhaps, most palatable when prepared as a blanc-mange with milk, but it should be eaten on the day it is made, being liable, when kept, to run to water. Its nourishing qualities have been tested, I am informed, in the successful rearing of calves and pigs partly upon it.

Many other species, particularly various kinds of *Grigartina* and *Gracilaria*, yield similar jellies when boiled, some of which are excellent.

Gracilaria lichenoides, the *Ceylon Moss* of the East, where it is largely used in soups and jellies, and *G. Spinosa,* the *Agar-Agar* (or Agal-Agal) of the Chinese, are among the most valuable of these. They are extensively used, and form important articles of traffic in the East. Another species of excellent quality (the *Gigartina speciosa* of Sonder) is collected for similar purposes by the colonists of Swan river.

It was at one time supposed that the famous edible birds' nests of China, the finest of which sell for their weight in gold, and enter into the composition of the most luxurious Chinese dishes, were constructed of the semi-decomposed branches of some Alga of one or other of the above-named genera; but it has since been ascertained that these nests consist of an animal substance, which is supposed to be disgorged by the swallows that build them.

Nearly all the cartilaginous kinds of Rhodospermeæ will boil down to an edible jelly. One kind is preferred to another, not from being more wholesome, but from yielding a stronger and more tasteless gelatine. The latter quality is essential; for though the skill of the cook can readily impart an agreeable flavor to a tasteless substance, it is more difficult to overcome the smack of an unsavory one. And the main quality which gives a disrelish to most of our Algæ-jellies and blanc-manges is a certain bitterish and sub-saline taste which can rarely be altogether removed.

Very few Algæ have been found agreeably tasted when cooked, though *Dillisk* and others are pleasantly sweet when eaten raw. Many which, when moistened after having been dried, exhale a strong perfume of violets, are altogether disappointing to the palate.

Perhaps, after all, the most valuable as articles of food are the varieties of *Porphyra vulgaris* and *P. laciniata*, which, in winter, are collected on the rocky shores of Europe, and by boiling for many hours are reduced to a dark brown, semi-fluid mass, which is brought to table under the name of *marine sauce, sloke, slouk,* or *sloucawn.* It is eaten with lemon-juice or vinegar, and its flavor is liked by most persons who can overcome the disgust caused by its very unpleasant aspect. At some of the British establishments for preserving fresh vegetables it is put up in hermetically sealed cases for exportation and use at sea, or for use at seasons when it cannot be obtained from the rocks. It is collected only in winter, at which season the membranous fronds, which are found in a less perfect state in summer, are in full growth. Both species of *Porphyra* grow abundantly on the rocky shores of North America. They not only furnish an agreeable vegetable sauce, but are regarded as anti-scorbutic, and said to be useful in glandular swellings, perhaps from the minute quantity of iodine which they contain.

As articles of food for man other seaweeds might be mentioned, but I admit that none among them furnish us directly with valuable esculents; though many less nauseous than the hunter's "*Tripe de Roche*" are sufficiently nourishing to prolong existence to the shipwrecked seaman; and others, like the *Porphyræ* just mentioned, are useful condiments to counteract the effects of continued subsistence on salt-junk.

But if not directly *edible*, there are many ways in which they indirectly supply the table. As winter provender for cattle, some are in high esteem on the northern shores of Europe. In Norway and Scotland the herds regularly visit the shores, on the recess of the tide, to feed on *Fucus vesiculosus* and *F. serratus*, which are both also collected and boiled by the Norwegian and Lapland peasants, and, when mixed with coarse meal, given to pigs, horses, and cattle. These Fuci are both grateful and nourishing to the animals, which become very partial to such food. Yet, perhaps, they are only the resources of half-fed beasts, and would possibly be blown on by a stall-fed "short-horn" that looks for vegetables of a higher order.

To obtain such food for the high-bred cow, the Algæ must be applied in another way—namely, as manure. For this purpose they are very largely used in the British islands, where "sea-wrack" is carried many miles inland, and successfully applied in the raising of green crops. On the west coast of Ireland, the refuse of the sea furnishes the poor man with the greater part of the manure on which he depends for raising his potatoes. All kinds of seaweed are indiscriminately applied; but the larger kinds of *Laminariæ* are preferred. As these rapidly decompose, and melt into the ground, they should, in common with other kinds, be used fresh, and not suffered to lie long in the pit, where they soon lose their fertilizing properties. The crops of potatoes thus raised being generally abundant, but the quality rarely good, sea-wrack is more suitable to the coarser than to the finer varieties of the potato. It is, however, considered excellent for various green crops, and a good top-dressing for grass land, and its use is by no means confined to the poorer districts. The employment of sea-wrack is limited only by the expense of conveying so bulky a material to a distance from the sea or a navigable river.

Though the agricultural profits derived from the Algæ are considerable, a still larger revenue was once obtained by burning the *Fuci* and collecting their ashes, as a source of carbonate of soda—a salt which exists abundantly in most of them. *Fucus vesiculosus, nodosus,* and *serratus*, the three commonest European kinds, yielded, up to a recent period, a very considerable rental to the owners of tidal rocks on the bleakest and most barren islands of the north of Scotland, and on all similar rocky shores on the English and Irish coasts. A single proprietor (Lord Macdonald) is said to have derived £10,000 per annum, for several successive years, from the rent of his *kelp* shores; and the collecting and preparation of the *kelp* afforded a profitable employment to many thousands of the inhabitants of Orkney, Shetland, and the Hebrides.

During the last European war, when England was shut out from the markets from which a supply of soda was previously obtained, almost the whole of the alkali used by soap-boilers was derived from the *kelp*, or sea-weed ashes, collected in Scotland. The quantity annually made in favorable years, between 1790 and 1800, amounted, on the authority of Dr. Barry,* to 3,000 tons, which then fetched from £8 to £10 sterling per ton; but, at a later period of the war, rose from £18 to £20. It is also stated by the same author, that within the 80 years, from 1720 to 1800, which succeeded the first introduction of the kelp trade, the enormous sum of £595,000 was realized by the proprietors of kelp shores and their tenants and laborers.

Yet, so great was the prejudice of the islanders against this lucrative trade, when first proposed to them, "and," to quote Dr. Greville, "so violent and unanimous was the resistance, that officers of justice were found necessary to protect the individuals employed in the work. Several trials were the consequences of these outrages. It was gravely pleaded in a court of law, 'that the suffocating smoke that issued from the kelp kilns would sicken or kill every species of fish on the coast, or drive them into the ocean far beyond the reach of the fishermen; blast the corn and grass on their farms; introduce diseases of various kinds; and smite with barrenness their sheep, horses, and cattle, and even their own families.'" We smile at the ignorant bigotry of these poor people; but have we never heard as great misfortunes predicted of almost every new improvement of the age we live in, and that not by unlettered peasantry, but by persons calling themselves wise, learned, and refined?—as sad stories have been told against temperance, free trade, or even against the exhibition in the Crystal Palace.

The Orkney islanders were not long in finding the golden harvest which had thus, in the first instance, been forced upon them, and, within a few years, "Prosperity to the kelp trade!" was given as the leading toast on all their festive occasions. This state of prosperity lasted until the general peace, when the foreign markets being thrown open, *barilla* came into competition with the home produce. The manufacture of kelp gradually declined as the price fell, and now it has nearly ceased altogether; for, besides the competition with *barilla*, the modern process by which soda is readily procured from rock-salt, has brought another rival into the field, and one against which it seems in vain to contend.

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* History of the Orkney Islands, p. 383, (as quoted by Greville; see Alg. Brit. Introd., p. xxi, et seq.)

Kelp is still made, on a small scale, for local consumption, and is sometimes exported as manure, but at a very low price. It is not likely ever to rise again into importance, except as a source of *Iodine*, which singular substance was first discovered in a soap-ley made with kelp ashes. Iodine has now become almost indispensable, from its medicinal value, as well as from its use in the arts and manufactures, and has been found in greater quantity in the fronds of certain littoral Algæ than in any other substances. It is therefore possible that, for producing this substance, these kelp-weeds may again become of mercantile importance. As a remedy in cases of glandular swellings, the use of Iodine is now well established, and it is a singular fact that several littoral Fuci have been from early times considered popular remedies in similar affections. *Fucus vesiculosus* has long been used by the hedge-doctors to reduce such swellings; and Dr. Greville mentions, on the authority of the late Dr. Gillies, that the "stems of a seaweed are sold in the shops, and chewed by the inhabitants of South America, wherever goitre is prevalent, for the same purpose. This remedy is termed by them Palo Coto, (literally, Goitre-stick,") and Dr. Greville supposes, from the fragments which he had seen, that it is a species of Laminaria.

Iodine, however, though the most important, is not the only medicinal substance obtained from the Algæ. *Gracilaria helminthochorton*, or *Corsican Moss*, has long held a place in the pharmacopœia as a vermifuge. What is sold under this name in the shops, is commonly adulterated with many other kinds. In samples which I have seen, the greater part consisted of *Laurencia obtusa*, through which a few threads of the true *Corsican Moss* were dispersed. Possibly, however, the *Laurencia* may be of equal value.

Mannite also has been detected by Dr. Stenhouse in several Algæ, to which it imparts a sweetish taste. The richest in this substance appears to be *Laminaria saccharina*, from a thousand grains of which 121.5 grains, or 12.15 per cent., of mannite were obtained. The method of extracting is very simple. The dried weed is repeatedly digested with hot water, when it yields a mucilage of a brownish-red color, and of a sweetish, but very disagreeable taste. When evaporated to dryness, this mucilage leaves a saline semi-crystalline mass. This being repeatedly treated with boiling alcohol, yields the mannite in "large hard prisms, of a fine, silky lustre." *Halidrys siliquosa*, *Laminaria digitata*, *Fucus serratus*, *Alaria esculenta*, *Rhodymenia palmata*, &c., are stated by Dr. Stenhouse, from whose memoir this account is condensed, to contain from 1 to 5 or 6 per cent. of mannite.

In summing up the economic uses to which Algæ have been applied, I must not omit to mention their application in the arts. The most valuable species, in this point of view, with which we are acquainted, is the *Gracilaria tenax* of China, under which name probably more than one species may be confounded. Of this plant, on the authority of Mr. Turner, (Hist. Fuc. vol. 2, p. 142,) "the quantity annually imported at Canton is about 27,000 lbs., and it is sold in that city at about 6d. or 8d. per lb. In preparing it, nothing more is done than simply drying it in the sun; after which it may be preserved, like other Fuci, for any length of time, and improves by age, when not exceeding four or five years, if strongly compressed and kept moist. The Chinese, when they have occasion to use it, merely wash off the saline particles and other impurities, and then steep it in warm water, in which, in a short time, it entirely dissolves, stiffening, as it cools, into a perfect gelatine, which, like glue, again liquefies on exposure to heat, and makes an extremely powerful cement. It is employed among them for all those purposes to which gum or glue is here deemed applicable, but chiefly in the manufacture of lanthorns, to strengthen or varnish the paper, and sometimes to thicken or give a gloss to gauze or silks." Mr. Turner derived the above information respecting *G. tenax* from Sir Joseph Banks; but recent travellers tell us that *Gracilaria spinosa*, known colloquially as *Agal-agal*,* yields the strongest cement used by the Chinese, and that it is brought in large quantities from Singapore and neighboring shores to the China markets. Probably both species are esteemed for similar qualities.

Several Algæ are used in the arts in a minor way. Thus, according to Dr. Patrick Neill, knife-handles are made in Scotland of the stems of *Laminaria digitata*. "A pretty thick stem is selected, and cut into pieces about four inches long. Into these, when fresh, are stuck blades of knives, such as gardeners use for pruning or grafting. As the stem dries, it contracts and hardens, closely and firmly embracing the hilt of the blade. In the course of some months the handles become quite firm, and very hard and shrivelled, so that when tipped with metal they are hardly to be distinguished from hartshorn."

On the authority of Lightfoot,† the stems of *Chorda filum*, which often attain the length of thirty or forty feet, and which are popularly known in Scotland as "Lucky Minny's lines," "skinned, when half dry, and twisted, acquire so considerable a degree of strength and toughness," that the Highlanders sometimes use them as fishing lines. The slender stems of *Nereocystis* are similarly used by the fishermen in Russian America. In parts of England bunches of *Fucus vesiculosus* or *F. Serratus* are frequently hung in the cottages of the poor as rude barometers, their hygrometric qualities, which arise from the salt they contain, indicating a change of weather.

In our account of the artistic value of Algæ, we ought not to pass unnoticed the ornamental works which the manufacturers of "seaweed pictures," and baskets of "ocean-flowers," construct from the various beautiful species of our coasts, and which are so well known at charity bazaars, accompanied by a much-hackneyed legend, commencing,

> "Call us not weeds; we are flowers of the sea," &c.

Some of these "works of art" display considerable taste in the arrangement, and the objects themselves are so intrinsically beautiful that they can rarely be otherwise than attractive. During the recent pressure of Irish famine, many ladies in various parts of the country employed a portion of their leisure in the manufacture of

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* See the Voyage of H. M. S. *Samarang*.

† Fl. Scot. vol. 2, p. 964.

these ornamental works, and no despicable sum was raised by the sale.

Other sums, for charitable purposes, have been realized in a way which a botanist would deem more legitimate, by the sale of books of prepared and named specimens; and my friend, the Rev. Dr. Landsborough,* I am told, has in this manner collected money which has gone a considerable way towards building a church. There seems no good reason why missionaries in distant countries might not, either personally or through their pupils or families, collect these and other natural objects, and sell them for the benefit of their mission; by which means they would not only obtain funds for pursuing the work more immediately committed to them, but would have the satisfaction of knowing that in doing so they were unfolding to the admiration of mankind new pages of the wide-spread volume of nature.

Unfortunately, it happens that in the educational course prescribed to our divines, natural history has no place, for which reason many are ignorant of the important bearings which the book of Nature has upon the book of Revelation. They do not consider, apparently, that both are from God—both are His faithful witnesses to mankind. And if this be so, is it reasonable to suppose that either, without the other, can be fully understood? It is only necessary to glance at the absurd commentaries in reference to natural objects which are to be found in too many annotators of the Holy Scriptures, to be convinced of the benefit which the clergy would themselves derive from a more extended study of the works of creation. And to missionaries, especially, a minute familiarity with natural objects must be a powerful assistance in awakening the attention of the savage, who, after his manner, is a close observer, and likely to detect a fallacy in his teacher, should the latter attempt a practical illustration of his discourse without sufficient knowledge.† This subject is too important for casual discussion, and deserves the careful consideration of those in whose hands the education of the clergy rests. These are not days in which persons who ought to be our guides in matters of doctrine can afford to be behind the rest of the world in knowledge; nor can they safely sneer at the "knowledge that puffeth up," until, like the Apostle, they have sounded its depths and proved its shallowness.

Why should the study of the physical sciences be supposed to have an evil influence on the mind—a tendency to lead men to doubt every truth which cannot be made the direct subject of analysis or experiment? I can conceive a one-sided scientific education having this tendency. If the mind be propelled altogether in one direction, and that direction lead exclusively to analytical research, it is possible that the other faculties of the individual may become clouded or enfeebled; and then he is the unresisting slave of analysis—not more a rational being than any other monomaniac. And yet, paradoxical though the assertion seem, he may be all his life a reasoner, forming

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* Author of "A Popular History of British Seaweeds."

† See some excellent observations on this subject in "Foot-prints of the Creator; or, the Asterolepis of Stromness," by Hugh Miller. London, 1849.

deductions and inductions with the most rigid accuracy in his beaten track.

I can conceive, too, the astronomer, conversant with the immensity of space and its innumerable systems of worlds, so prostrated before the majesty of the material creation, as not only to lose sight of himself and of the whole race to which he belongs, but of the world, or even of the solar system, and be led to doubt whether things so poor, and mean, and small can have any value in the sight of the Lord of so wide a dominion. I can conceive him, too, observing the uniformity and the harmony of the laws that govern the whole system of the heavens; the undeviating course of all events among the stars coming round as regularly as the shadow on the dial; and the little evidence there is that this uniformity has ever suffered any disturbance that cannot be accounted for by the law of gravitation, and made the subject of calculation by the mathematician, who, working an equation in his closet, shall come forth and declare the cause of irregularity, though that cause may be acting at thousands of millions of miles distance—I can conceive him inferring from a uniformity like this the absence of a superintending Providence in human affairs. If the Creator, he will say, have given up the very heaven of heavens to the immutable laws of gravitation, can I believe that he interferes by his Providence to superintend the puny matters of this lower world?

His reasons seem plausible while the mind is pointed in that one direction. But they lose all their force when, laying aside for a moment the telescope, the philosopher investigates with his microscope the structure of any *living* thing, no matter how small and how seemingly simple the organism may be. Let the object examined but have *life*, and it will soon lead him to understand a little of the meaning of God's glorious title, *Maximus in minimis*. And the further he carries his researches, the more the field of research opens, until, extending from the speck beneath his lens, it spreads wider and wider, and at length blends with infinity at the "horizon's limit." Here his boasted analysis can afford him no help. He has laid bare the "mechanism of the heavens;" he has weighed the sun and the planets; he has foretold with unerring certainty events which shall happen a thousand years after he shall be laid in the dust: and yet he cannot unravel the mystery that shrouds the seat of life, even as it exists in the meanest thing that crawls. And if the life of this poor worm be thus wonderful, what is that spirit which animates the human frame? What is that humanity which, but a moment ago, seemed like the small dust in the balance compared with the multitude and the masses of the stars? His conceptions of his own true position in the scale of being become more rational. For a moment he views from a new position the distant stars, as the peasant views them in a clear night—points of light spangling the blue vault above. And he reflects, "How do I *know* that those shining ones are other than they seem? How do I *know* their size, their distance, the laws by which they are governed—the reins by which the 'coursers of the sun' are held in their appointed track? How, but by the intellectual powers of that human spirit which but now I deemed so poor and mean, so unworthy of the very thought of the Almighty—much more, so unworthy of the price which He has paid for it?"

Thus the mind, turned back upon itself, begins to discover that, after all, it is not "of the earth, earthy," but derived from a higher source, and reserved for a higher destiny. And, strange to say, this altered and bettered opinion of itself is traceable to the first check which it feels—the first baffling of its analytical powers. So long as the mind was extending the sphere of its researches into the material universe, weighing, and numbering, and tabulating, all nature seemed to move in blind obedience to a force whose influence might be calculated; every world being found to act upon its fellow in exact proportion to its position and its weight, and *our* world to be but a part, and a small part, of one vast machine. And with such a view of the relation of the earth to the universe, might not unnaturally come a lower estimate of man, the dweller on the earth. "Is he, too, but a part in the house in which he dwells? Is his course also subject to those immutable laws which bind the universe together? And, if so, where is his individuality? Where the reflex of that image in which he is said to have been created?" But the moment that the mind apprehends the action of the inexplicable laws of life, and is certified of the *individuality* of every living thing, however small, and compares these microscopic "wholes" with the "whole" that it feels itself to be, that moment it begins to see that the human soul is a something apart from the world, in and over which it is placed.

Galileo in his cell was bound in fetters, but his spirit could not be bound. His thoughts were as free, and his mind had as wide a range, as if he could have flown through all space on the wings of light. And thus it is with man—prisoned for a short time in this lower world, he belongs to an order of being that no world can confine. He cannot continue stationary, nor plod forever a dull round in the treadmill here. He must either rise above all height, into communion with the Deity; or fall, bereft of hope, forever. We must not estimate such a being by the narrow bounds of the cell which he now inhabits. We must judge of him by his intellectual powers, his aspirations, his intuitive conceptions of his own nature; and, as a spirit, all these place him, in his *individuality*, far above any plurality of mere material worlds.

I may seem to be wandering from my proper theme, but my object is to vindicate the teaching of the Book of Nature from the aspersions of the ignorant and the prejudiced. Whilst I admit that half views of natural science may lead men astray, and whilst I deplore the infidelity of scientific men whose minds are absorbed in the material on which they work, I deny that the study of nature has, in itself, an evil tendency. On the contrary, the study of organic nature, at least, ought to be one of the purest sources of intellectual pleasure. It places before us structures the most exquisite in form and delicate in material; the perfect works of Him who is Himself the sum of all perfections:—and if our minds are properly balanced, we shall not rest satisfied with a mere knowledge and admiration of these wonderful and manifold works; but, reading in them the evidence of *their* relation to their Maker, we shall be led on to investigate *our own.*

I do not assert that this study is, of itself, sufficient to make men religious. But as the contemplation of any great work of art generally excites in us a two-fold admiration—admiration of the work itself, and of the genius of its author—so a true perception of the wonders of nature includes a certain worship of the author of those wonders. Yet we may study natural objects, and admire them, and devote our whole life to elucidate their structure; and after all may fail to recognise the being of Him who has fashioned them. Such blindness is scarcely conceivable to some minds; yet to others, the opposite appears but the effect of a warm imagination. So inexplicable is the human mind! The moral evidence which stirs one man to his centre brings no conviction to another. Physical truths, indeed, cannot be rationally denied; but there is no metaphysical truth which may not be plausibly obscured or explained away by self-satisfied prejudice. Hence the inconclusiveness of all reasoning against infidelity. The failure is not in the reasons set before the mind, but in the non-acknowledgment of the imperative force of moral reasons. No man can be convinced of any *moral* truth against his will; and if the will be corrupt, it is possessed by a blind and deaf spirit, which none can cast out until a "stronger than he" shall come.

Here I pause; but I cannot conclude this lecture without expressing my warm thanks to the kind friends who have aided me in my researches, both with specimens and with sympathy. To some of them I am personally unknown, and with others I became acquainted casually, during my recent tour along the shores of the United States. From all I have received unmixed kindness, and every aid that it was in their power to render. Indebted to all, therefore, I am more especially bound by gratitude to my friend, Professor J. W. BAILEY, of West Point, the earliest American worker in the field of Algology. Well known in his own peculiar branch of science, he has found a relaxation from more wearing thought, in exploring the microscopic world, and his various papers on what may be called "vegetable atoms" (*Diatomaceæ*) are widely known and highly appreciated. From him I received the first specimens of United States Algæ which I possessed, and, though residing at a distance from the coast, he has been of essential service in infusing a taste for this peculiar department of botany among persons favorably situated for research; so that either from him or through him I have obtained specimens from many localities from which I should otherwise have been shut out. To him I am indebted for an introduction to a knot of Algologists who have zealously explored the southwestern portions of Long Island and New York Sounds, Messrs. HOOPER, CONGDON, PIKE, and WALTERS of Brooklyn, from all of whom I have received liberal supplies of specimens; and through him Professor LEWIS R. GIBBES, of Charleston, whose personal acquaintance I had afterwards the happiness of making, first communicated to me the result of his explorations of Charleston harbor, as well as the first collection of Florida Algæ which I received, and which Dr. Gibbes obtained from their collector, the late Dr. Wurdemann. Through Professor ASA GRAY, of Cambridge, Mass., long before it was my good fortune to know him personally and intimately, I received collections of the Algæ of Boston harbor, made by Mr. G. B. EMERSON, Miss MORRIS, and Miss LORING, (now Mrs. GRAY); also of the Algæ of Rhode Island, made by Mr. S. T. OLNEY, who has done so much to illustrate the botany of that State, and by Mr. GEORGE HUNT. My gatherings from the same coasts have since been much enriched by specimens from Dr. SILAS DURKEE, of Boston, Dr. M. B. ROCHE, of New Bedford, and Mrs. P. P. MUDGE, of Lynn.

To Professor TUOMEY, of the University of Alabama, I feel especially indebted for the care and kindness with which he formed for me an interesting collection of the Algæ of the Florida Keys, and the more so because this collection was made purposely to aid me in my present work. My friend Dr. BLODGETT, of Key West, also, since my return to Europe, has communicated several additional species, and is continuing his researches on that fertile shore. To the Rev. W. S. HORE, now of Oxford, England, (a name well known to the readers of the Phycologia Britannica,) I am indebted for a considerable bundle of well preserved specimens, gathered at Prince Edward's Island, by Dr. T. E. JEANS; and to the kindness of my old friend and chum, ALEXANDER ELIOTT, of the Dockyard, Halifax, I owe the opportunity of a fortnight's dredging in Halifax harbor, and many a pleasant ramble in the vicinity.

My personal collections of North American Algæ have been made at Halifax; Nahant beach; New York Sound; Greenport, Long Island; Charleston harbor; and Key West; and are pretty full, especially at the last named place, where I remained a month.

The few Mexican species which find a place in my work have been presented to me by Professor J. AGARDH, of Lund, and were collected by M. LIEBMAN. Those from California are derived partly from the naturalists of Captain Beechey's voyage; a few from the late DAVID DOUGLAS; and a considerable number brought by my predecessor, Dr. COULTER, from Monterey Bay. I have received from Dr. F. J. RUPRECHT, of St. Petersburg, several Algæ from Russian America; from Sir JOHN RICHARDSON a few Algæ of the Polar sea; and various specimens of these plants, which have found their way from the Northwest Coast to the herbarium of Sir W. J. HOOKER, have, with the well-known liberality of that illustrious botanist, been freely placed at my disposal.

But I should not, in speaking of the Northwest Coast, omit to mention a name which will ever be associated in my mind with that interesting botanical region, the venerable ARCHIBALD MENZIES, who accompanied Vancouver, and whom I remember as one of the finest specimens of a green old age that it has been my lot to meet. He was the first naturalist to explore the cryptogamic treasures of the Northwest, and to the last could recal with vividness the scenes he had witnessed, and loved to speak of the plants he had discovered. His plants, the companions of his early hardships, seemed to stir up recollections of every circumstance that had attended their collection, at a distance of more than half a century back from the time I speak of. He it was who first possessed me with a desire to explore the American shores—a desire which has followed me through life, though as yet it has been but very imperfectly gratified. With this small tribute to his memory, I may appropriately close this general expression of my thanks to those who have aided me in the present undertaking.

LECTURE.

NATURAL HISTORY AS APPLIED TO FARMING AND GARDENING.

BY REV. J. G. MORRIS, OF BALTIMORE.

The lecturer commenced by observing, that every American has reason to be proud of the exploits of his countrymen in the field of natural history. Extended tours have been made, and exhausting fatigues have been cheerfully endured; the most patient investigation has been instituted, and many magnificent works have been published. Some of these equal, in splendor of pictorial illustration, those of any other country, and the literary portion will favorably compare with the most finished scientific compositions of the world. Audubon's great works on our birds and quadrupeds was here especially cited, whilst proper credit was given to other native illustrated works. The catalogue of our naturalists and their books is increasing every year, and the facilities for studying the natural history of our country are rapidly enlarging.

The lecturer mentioned the names of our principal naturalists, arranged under each branch which they have respectively investigated, including mammals, birds, reptiles, fishes, shells, crustaceans, and insects.

Whilst much has been accomplished, yet the whole field has not yet been explored. Our new western territorial acquisitions almost daily develop new animal treasures, and it will not be many years before the energy of our students of nature will push their researches to the utmost limits of our boundaries. Some interesting details were related of the self-denial and perseverance of our exploring naturalists, whose adventures have an air of romance truly enchanting.

Several of our State legislatures have made liberal appropriations for geological and zoological surveys. Massachusetts and New York were particularly noticed, and a description of the great works on these subjects, published by them, was given. He noticed the proposal to establish an agricultural college in a northern State some time ago, in which there was to be a professor of geology, which was well enough; but the lecturer maintained, that zoology should also be taught in such an institution, for the farmer should know the habits and names of the various animals which are injurious to vegetation, and the best method of checking the mischief done by them, as well as the nature of his various soils, which geology and agricultural chemistry teach. The farmer should also be acquainted with the grasses and forest-trees of his plantation, and thus elevate his noble profession to its proper rank among human pursuits, and feel that the exercise of intellect, as well as of muscle, is highly useful to his purpose.

The anatomical structure of his domestic animals should also be studied, so that he may understand the different diseases to which they are liable.

After an enlargment on the importance of our domestic animals, field products, and minerals, as sources of wealth and comfort, a few striking facts were given, demonstrating the immense benefit which a knowledge of the natural history of some animals and plants has conferred on mankind. Thus, Linné prevented the decay and destruction of the ship timber in the royal dock-yards of Sweden, by knowing the habits of the little insect which occasioned the evil. It was the same naturalist who first advised the sowing of beach-grass (*Arundo arenaria*) to prevent the encroachments of the sea, by fixing the sands of the shore, in Holland, and this has been tested to some extent in Massachusetts.

Farmers and gardeners often complain of their fruit being devoured by birds and other "*vermin*," as many call them, and an indiscriminate slaughter ensues. It is time that correct notions on this subject should prevail, and all would soon be right if natural history were included in the range of general reading.

In proceeding with the lecture, the vertebrate animals that are supposed to be noxious to vegetation were considered. The *mammals* were first mentioned. The operations of foxes, rats, weasels, rabbits, moles, field-mice, squirrels, &c., were alluded to. It was stated that an English nobleman, instead of destroying the moles in his grounds, offered a reward for bringing them to him, being assured that they were more beneficial than injurious, inasmuch as, in their subterranean wanderings, they destroyed immense numbers of noxious grubs and beetles.

The *birds* were next considered, and the conclusion adopted, that the destruction of birds has given rise to an infinitely more prejudicial multiplication of noxious insects than the evils they themselves occasioned. The opinions of eminent naturalists on this subject were cited, confirmatory of this opinion.

Having considered the *vertebrates*, or those with a backbone, in relation to this subject, the *invertebrate insects*, particularly, were next introduced. It was stated, that they are greater pests and commit greater ravages, and annoy the farmer and gardener more, than all other noxious animals together.

After dilating in general on the study of entomology, and the importance of insects in the economy of nature, the lecturer proceeded to speak of those insects which affect our *field crops*, *garden plants*, *flowering plants*, and, finally, *our fruit and forest trees*.

Wheat was placed at the head of field crops. Here, naturally, the *Hessian fly* first demanded attention. Of this diminutive insect it has been properly said, "that it is more formidable than an army of 20,000 Hessians would be."

Its history was given, and it was made out to be an European insect, and introduced in August, 1776, by the Hessians, who landed on

Staten Island, and was brought in the straw used in packing. It was in that vicinity that it first attacked the wheat-fields, and thence spread over the country. It was totally unknown in this country before the Revolution. Its ravages soon began to excite the attention of farmers. Whole crops were destroyed. Learned societies and agricultural associations offered rewards for its extirpation. The American Philosophical Society, in 1792, appointed a committee, consisting of Mr. Jefferson, B. Smith Barton, James Hutchinson, and Caspar Wistar, to collect and communicate materials for the natural history of the Hessian fly. So greatly was it dreaded in England, that in 1788 an order was issued by government, prohibiting the entry of wheat from the United States into any of the ports of Great Britain. This order was based on ignorance of the habits of the insect, for it is not the grain that is affected by it, but the plant alone. It could not be transported in the grain. The history of the little depredator was given at length, and its form, &c., illustrated by large drawings.

Its character and transformations, and the mode of its operations on the wheat-stalk, were enlarged on. After describing its depredations, it was observed, that if Providence had not provided an effectual means of checking its ravages, they would literally swarm over the land. *This insect is preyed on by at least four others*, which were briefly described. Proper credit was awarded to Dr. Fitch and Mr. Herrick for their interesting and successful investigations on this subject. The various remedies proposed were also noticed, but none, as yet, appears infallible. A rich soil, late sowing, grazing, rolling, mowing, steeps for the seed, &c., &c., have all been suggested.

The history of another insect infesting our wheat was given, closely allied to that already considered. This is the *wheat fly*. They are, by many, considered the same; and hence errors and confusion have arisen. This insect deposites its eggs, not like the Hessian fly, in the blades of the plant, but in the chaffy scales of the flowers. The larva works its way into the grain, lives upon its juices, and thus destroys it. It has, however, powerful enemies in some parasites, but especially in our common yellow bird, (*Fringilla tristis.*)

There are other insects which attack stored grains—as a small weevil (*Calandra remote punctati*) and a small moth, (*Alucita cerealella,*) &c., &c.

Indian Corn—This plant is attacked principally by the larva of a moth, (*Gortyna zeæ,*) which penetrates into the soft centre of the stalk near the ground, which destroys it. There is the larva of another moth, (*Agrotis segetum,*) which attacks the roots and tender sprouts of the young plants. This is familiarly known as the *cut-worm*, though several destructive worms are known by that name. Various remedies have been proposed for these depredators, but none, probably, effectual.

Grass.—This is attacked by the grub of a beetle, (*Melolontha quercina.*) The roots are devoured by it. The *wire-worm*, which is the larva of a beetle, (*Elater obesus,*) is also exceedingly destructive to grass.

In relation to *garden plants*, the lecturer enumerated the insects most destructive, and the various methods of exterminating them.

The insects injurious to *fruit trees* were more particularly considered. The history of those attacking the apple, peach, pear, plum, cherry, grape, &c., was given, and the proper means of destroying them.

The *forest trees* of our country have not yet received the scientific consideration they deserve—that is, as to their economical importance. They have been named and described, and some splendid illustrated works have been published upon them, but they have not been cultivated with care, and no attention is paid to their preservation. This is owing to their vast numbers, and it will probably be a century hence before we shall find it necessary to have a public officer, as they have in Europe, whose special duty it shall be to superintend the woods and forests.

Our common *hickory* tree is sometimes much injured by a beetle, (*Areoda lanigera.*) The grubs of the beautiful family of beetles (*Buprestidœ*) are wood eaters and borers. The solid trunks and limbs of sound and vigorous trees are often bored through in various directions by them, and, of course, destroyed. The grub of a capricorn beetle (*Stenocorus garganicus*) inhabits the hickory, and forms long galleries in the trunk.

The *oaks* are attacked by the larva of *Elaphidion putator*, which perforates the small branches to the extent of six or eight inches. It lives in the pith, and, when it is full-fed, it eats away all the wood transversely from within, leaving only the ring of the bark untouched. It then retires backwards, stops up the end of its hole near the transverse section with the fibres of the wood, and the next strong wind breaks off the twig, precipitates it to the ground, the larva then comes out, buries itself in the earth, and there undergoes its transformation.

The *pine* trees in this country, as well as in Europe, have also suffered much from an insignificant beetle. Its ravages have been extensive. A few years ago there were loud complaints of the depredations of a certain insect on the pine trees of the South, but people, for the most part, did not know what it was. It is a small beetle, (*Hylobius pales*, or *picivorus.*)

The *elm* trees in New England, or rather their foliage, is destroyed by what is there called the *canker-worm.* It is the larva of a small butterfly, which is hatched from the egg of the *wingless* female. She climbs up the tree by its trunk. To prevent this, the trunk, near the top, is encircled by a leaden trough, filled with tar or oil, and this prevents the female from reaching the leaves, on which she deposites her eggs. For some years back, the elm trees of our State have been denuded by the larva of an insect. People had heard of the means employed in New England to prevent the ravages of the worm, and soon many of our elm trees were furnished with leaden troughs, but the insect was as mischievous as ever. What was the reason? Simply this, that the insect in New England is an entirely different one from ours. That is a *butterfly*, the wingless female of which is obliged to crawl up the trunk of the tree; ours is a *beetle*, the winged female of which *flies* to the tree, and, of course, the leaden trough on the trunk will not interfere with its depredations. It is the *Galeruca calmariensis*, and is of foreign introduction.

The injuries done to the cedar, locust, and other trees, by insects, were severally considered.

The Doctor concluded by observing that, if men undertake to destroy insects, they should know their economy, for otherwise those might be destroyed which are really beneficial. In some countries children are employed for this purpose; and to give an idea of the numbers of some species of noxious insects, he stated an instance related by Mons. Audouin, who was charged by the French Academy of Science to investigate the habits of a small moth, whose larva was found to be exceedingly injurious in vineyards in France. During the month of August, women and children were employed for four days in collecting the patches of eggs upon the leaves, during which period 186,900 patches were collected, which was equal to the destruction of 11,214,000 eggs. In twelve days, twenty or thirty workers destroyed 40,182,000 eggs; all of which would have been hatched in twelve or fifteen days.

The intimate connexion in which insects stand to man, to domestic animals, and to vegetable productions, makes them well worthy the consideration of every one, and particularly of the farmer and gardener. If we consider the fecundity of many kinds, which sometimes produce an offspring of several thousands, and also that some species produce several generations in one season, their numbers cannot be estimated. All these uncounted myriads derive their nourishment either from plants or animals in their living state, or from their remains when dead. From such considerations, we may well be alarmed for our fields, forests, and gardens.

It would be well for farmers and gardeners to observe closely, and communicate their observations through the journals of the day. We, too, after awhile, may have a great national work on this subject, as most European governments have. Our government, or some well-endowed institution, could not more usefully spend a sum of money; and it is hoped that when an agricultural bureau shall have been established here at Washington, we shall have such a work that shall be worthy the subject and worthy the nation.

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LECTURE.

INSECT INSTINCTS AND TRANSFORMATIONS.

BY REV. J. G. MORRIS, OF BALTIMORE.

The lecturer began by deploring the neglect of the study of entomology in this country, and gave several reasons why the science has not been cultivated to the same extent as some other branches of zoology, such as the minuteness of insects, the presumed difficulty of capturing them, the dislike to killing them, their increased numbers, the dread many persons have of handling them when living, the scarcity of books describing our own species, the fear of being ridiculed by others, &c., &c. In illustration of the latter reason, he related an anecdote of an English lady of fortune, whose will some disappointed heirs wished to break on the ground of insanity at the time it was made; and one reason they strongly urged to prove her disordered intellect was, that she was fond of catching butterflies, and studying the habits of insects in general!

The lecturer proceeded to show that the ever-varying wonders which the natural history of insects presents, are much more remarkable than those of other classes of animals. The curious construction of their frame, their diversified colors, their wonderful instincts, their extraordinary transformations, their beauties and uses, render them objects worthy of investigation. He showed how extensively the science had been cultivated in Europe, and gave a brief history of it from the days of Linné to the present time. He mentioned the names of some of the most distinguished writers of the present day, and stated some interesting facts relative to the character and immense cost of some of the illustrated books on the subject. He paid a deserved compliment to the few entomologists of our own country, and specially cited the names of Say, Melsheimer, (father and sons,) Harris, LeConte, Randall, Haldeman, Ziegler, Fitch, and a few others, who had industriously pursued the subject.

The difficulties to beginners in this science were alluded to, but it was demonstrated that no branch of zoology afforded more pleasure in its prosecution; and here a general view was taken of the curious habits of some insects—the arrangement and character of their eyes, their motions, food, societies, habitations, eggs, affection for their young, injuries, benefits, propagation, geographical distribution, infinite numbers, inexhaustible variety, unequalled beauty, which the highest skill of the painter cannot imitate; their stratagems in the pursuit of their prey, their inconceivable industry, and some other wonderful phenomena.

After this general view, the lecturerer dwelt specifically on several points; and, first, on the *Transformations of Insects.* Everybody would be surprised to see a bird of gorgeous plumage rise out of the earth, proceeding from a serpent-like worm that had buried itself and remained under ground for several years. This would be an extraordinary metamorphosis, and yet the equivalent of this is occurring every day during the summer. 'The butterfly, which sports in the air, and sips nectar from every flower, was nothing once but a crawling caterpillar, which, entombing itself in the coffin or cocoon of its own construction, or changing into a chrysalis, came forth at last the beautiful animal you now behold it, with its habits, food, appearance, organs, entirely changed. And the same is true of nearly all insects.

The different states of insects were now spoken of: the egg, larva or grub, chrysalis and imago, or perfect insect, and the peculiarities of each dwelt upon. The different modes of transformation were mentioned, and some of them were illustrated in full. Many curious and striking facts in connexion with this head were introduced. The habits of the ichneumon flies, which lay their eggs in caterpillars, by inserting their ovipositors through their flesh, the larvæ of which feed on the fatty juices of the living caterpillar, and undergo their transformation in the body, and eat their way out as the perfect insect.

The *benefits* and *uses* of insects were then exhibited. They are nature's scavengers; the carcases of animals are speedily consumed by the larvæ of various beetles and flies, and there is good ground for Linné's assertion that three flies of a certain species will devour a dead horse as quickly as a lion. Each will produce 20,000 grubs, which, in twenty-four hours, will devour so much food as to increase their bulk two hundred fold. The burying beetle inhumes small dead animals, and ants perform no mean office in this respect. Putrescent vegetables and decomposing fungi are consumed by beetles, and stagnant waters are purified by innumerable larvæ. Noxious insects are kept within proper limits by others; wasps destroy multitudes of spiders and grasshoppers, and the family of ichneumon insects kill thousands of caterpillars. If it were not for the larvæ of the lady-bird, so common in our gardens, our roses, and some other flowers, would be destroyed by the parasitic animals upon them. The singular ant-lion, which lies in wait for its prey in a hole in the sand, and most curiously *throws stones* at its retreating game, destroys many noxious insects. Nothing escapes the ruthless attacks of the ichneumons; they assault the spider in his web, the bee in his retreat; they find out the larvæ of the Hessian fly and kill millions of them. The tiger-beetle preys on the whole insect race, and the water-beetles are no less cruel on their congeners. Ants, wasps, hornets, dragon-flies, in a word nearly all are employed by Providence in keeping down a superabundance of these little animals, which, if left unmolested, would be a plague on the earth. Insects are real cannibals; even some species of caterpillars will devour each other. Some devour their own offspring with savage ferocity, and the young of the mantis will fall on and devour each other as soon as they are excluded from the egg.

Insects, wholly or in part, constitute the food of some of our most esteemed fishes and birds; they afford nourishment to some quadrupeds and reptiles; many of them furnish the best bait to the angler. In some countries they are eaten and accounted great delicacies, and we who delight in lobsters, terrapins, and bullfrogs, should not be squeamish about the Arabs eating locusts, or some people in South America crunching a centipede with appetite, or making a savory soup of the grubs of beetles.

Many years ago, the doctors made extensive use of insects in their practice. Powder of silkworms was given for vertigo; millepedes for the jaundice; fly-water for ear-ache; five gnats were considered a dose of excellent physic; lady-birds for cholic and measles; ants were incomparable for leprosy and deafness. A learned Italian professor assures us that a finger once imbued with the juices of a certain beetle will retain its power of curing tooth-ache for a year!

But it is true that, in Cayenne, one insect produces a lint which is an excellent styptic, and gum ammonia oozes out of a plant from an incision made by another. The benefits and uses of the *Cantharis*, a Spanish fly, the cochineal, the gall-flies, the bee, silkworms, &c., &c., are well known.

Many interesting illustrations were given of the *affection which many insects have for their young*. The selection of the appropriate place for the deposite of their eggs by the butterfly, the dragonfly, the horsefly, the wasp, &c.; the gathering of proper food for the larvæ; their protection against natural enemies and the weather; these, and other curious facts under this head, were dwelt on at some length.

The phenomena presented by insect *habitations* were exhibited very lucidly. The lecturer stated and proved, that the most ingeniously constructed hut of the beaver, and the most artfully contrived nest of the bird, are far surpassed by the habitations of insects. Here he discoursed on the cells of wasps, and particularly of the honey-bee—and these latter were illustrated by large drawings—showing that the bee in the construction of its nest solves a problem in mathematics of the highest order. He related many interesting phenomena, which seemed almost incredible to those who had never paid special attention to this subject. He stated that Dr. Paley was mistaken in asserting "that the *human* animal is the only one which is naked, and the only one which can clothe itself," by showing that caterpillars of various moths clothe themselves comfortably and beautifully. Not only do larvæ which live on land construct coverings for themselves, but some which spend that period of their existence in the water. They make their coats of sand, grass, and sometimes of minute shells. The common web, or habitation of the spider, is familiar to all; but there is one species which excavates a gallery upwards of two feet in length and half an inch broad. It is furnished at the orifice with a curiously constructed door, actually turning on a hinge of silk, and, as if acquainted with the laws of gravity, she invariably fixes the hinge at the highest side of the opening, so that the door when pushed up shuts again by its own weight. The habitation of the water-spider is built under water, and is formed, in fact, of air. She first constructs a frame-work of her chamber attached to the leaves of aquatic plants; she then covers it with a sort of varnish elaborated from her spinner; she then introduces bubbles of air, and soon has a commodious and dry retreat in the water.

The *means of defence* which insects employ were also considered. They assume various attitudes calculated to deceive the beholder; many roll themselves up and feign death. One genus, *Brachinus*, has the wonderful faculty of producing a sound (but not from the mouth) like the explosions of a pop-gun, and a smoke-like secretion is at the same time discharged. Other insects eject an acrid fluid from their mouths; some defend themselves with their weapons; some have horns and strong claws; some have stings; some bite—others pierce; bees erect fortifications at the mouth of their hives to defend themselves against their enemy, the moth; some cover themselves with leaves; some appear only at night, &c., &c.

Numerous instances of the remarkable instincts of insects were given, and among them that of the common mosquito in the laying of its eggs. The female poises herself lightly on the water, protrudes her hinder legs crosswise, and deposites her eggs on the platform thus formed; and when she has laid all, to the number of three hundred, she lets the mass drop on the water, where they are hatched, and in which they are destined to live in their larva state. This mass of eggs is not a misshapen cluster, but it has the regular form of a boat, and is so well poised that the most violent agitation of the water cannot overset it. If it sunk, the eggs would perish; but they float until they are hatched, and then the young find their destined place in the water, in which they undergo their transformation. Other examples of instinct of caterpillars, wasps, ants, moths, &c., were given.

This led the lecturer, in conclusion, to say something on the nature of instinct itself.

The French naturalist, Bonner, has said that philosophers will in vain torment themselves to define *instinct*, until they have spent some time in the head of an animal, without actually being that animal! Cudworth referred this faculty to a certain *plastic nature;* and Des Cartes maintained that animals are mere machines. Mylius, an old philosopher, thought that many of the actions deemed instinctive are the effect of painful corporeal feelings; the cocoon of a caterpillar, for instance, being the result of a fit of cholic; the animal producing the cocoon by its uneasy contortions, and thus twisting its superabundant silk material into a regular ball. Some have thought that the brain of a bee or spider is impressed at its birth with certain geometrical figures, according to which models its works are constructed. Buffon refers the instinct of societies of insects to the circumstance of a great number of individuals being brought into existence at the same time, all acting with equal force, and obliged, by the similarity of their structure, and the conformity of their movements, to perform each the same movements in the same place, whence results a regular, well-proportioned, and symmetrical structure. Addison and some others have thought, as Kirby reports, that instinct is an immediate and constant impulse of the Deity. The only opinion which deserves serious consideration is that which contends for the identity of instinct with reason in man. Some great names are arranged on this side, and it is the view commonly taken by those who have not investigated the subject. It involves consequences which are dangerous, and, of course, erroneous.

If we allow reason to animals, we must admit some monstrous absurdities. The bee must be the best mathematician and philosopher; the young bird must be the best architect; the spider the best weaver; the beaver the best house-builder, &c., &c.

There is no progressive improvement in insect architecture; no labor-saving machinery employed; each species has its limited capacity, and there its powers cease; neither is instinct improved by domestication, &c.

The lecturer then returned to his specific theme, and by numerous examples showed that insect instinct seemed to be more *exquisite* than that of higher animals; they showed more cunning, more art, more *adaptation*, than other animals.

He closed by expressing the hope that he had awakened some interest in this long neglected subject. That though insects are small animals, yet "the meanest thing hath greatness in it," for all things bear the impress of the Almighty maker: *Omnia plena sunt Jovis;* and in our investigations into the secrets of nature, we are led to praise

"Him first, Him last, Him midst,
Him without end."

LECTURE.

OXYGEN AND ITS COMBINATIONS.

BY PROF. GEO. J. CHACE,
OF BROWN UNIVERSITY.

Combustion or the rapid union of bodies with oxygen, attended with the free evolution of light and heat, takes place only at temperatures more or less elevated. Phosphorus, the substance most readily ignited, does not kindle till it has been raised to 120° Fahrenheit. Sulphur, the next most inflammable body, must be raised to the temperature of 300° before it will begin to burn. Charcoal kindles only at the full red heat. Anthracite coal requires a temperature somewhat higher; while iron and most of the other metals must be brought to the glowing white heat before they will enter into combustion.

As this rapid union of bodies with oxygen takes place only where their affinities have been energized by rise of temperature, it rarely occurs in nature; never, in fact, except where the lightning falls upon the forest or the prairie, or the volcano sends forth its burning streams of lava. As ordinarily witnessed, it is brought about by artificial means for the attainment of economical and industrial ends.

In order that oxygen may unite with bodies at ordinary temperatures, it must be presented to them in connexion with water. Dry oxygen, whether pure or mingled with nitrogen, as in the atmospheric air, has no action upon them. With the single exception of potassium, all the metals may be exposed to it for an indefinite length of time without alteration. The most perishable organic substances in like manner remain unchanged in it. Neither do these bodies suffer change in water from which the air has been removed; but, exposed to the combined action of air and water, or rather to the action of air dissolved in water, all organic substances and nearly all the metals pass more or less rapidly into the state of oxides. It is in this way that oxidation in nature is universally effected.

The solvent powers of water are scarcely greater for solids than for gases. Of some of these it absorbs several hundred times its volume. For oxygen and nitrogen, however, the two principal constituents of the atmosphere, its affinity is less energetic. Of the former, it absorbs but 4½ per cent.; and of the latter, only 2½ per cent. of its volume. On account of the greater solubility of the oxygen, the air obtained from water is richer in this element than ordinary atmospheric air. This contains only about 20 per cent. of its volume of oxygen; while the air extracted from water contains more than 30 per cent. of its volume of oxygen.

As the water at the earth's surface is everywhere in contact with the air, it is always more or less perfectly saturated with it. Although the oxygen is continually being withdrawn by the respiration of aquatic animals, and also by decaying animal and vegetable matters, fresh portions of this element are as constantly taken in from the atmosphere. This process of absorption is materially facilitated by agitation at the surface of contact between the two fluids. Hence the winds play an important part in keeping the superficial portions of the oceans, seas, and lakes charged with oxygen.

Water is thus the great transferer of oxygen from the atmosphere to the various organic and mineral substances entering into union with it. The thinner the stratum of water interposed between the air and the oxydizing body, the more rapidly is the transfer effected. Hence metals with a mere film of water upon their surface, such as they gather from a damp atmosphere, corrode much faster than when deeply buried in that fluid. Metals with rough surfaces, also, when exposed to a damp atmosphere, rust sooner than metals whose surfaces have been polished. These latter, on account of their feebler attraction for moisture, do not so readily gather the requisite film of water; or if it be precipitated upon them, it quickly passes off by evaporation, as is seen in the case of the highly polished knife or razor.

If a sheet of iron be placed in a damp atmosphere, or in water containing air, the phenomena observed will be as follows: For a time the metal will retain its brightness and apparently suffer no change. At length, however, minute spots of rust make their appearance here and there upon its surface. These, when they have once begun to form, rapidly enlarge and multiply until ere long the entire sheet is overspread by them. This more rapid oxydation is probably caused by a change in the electric state of the metal. Little galvanic circles are formed by the spots of rust on the iron, in consequence of which the latter acquires an increased tendency to unite with oxygen. Whether the incipient oxydation is due to a similar influence of the water upon the iron, or whether it is owing to the oxygen being presented by the water in a state more favorable to combination, or whether both of these causes concur in determining it, may admit of question.

Copper, lead, tin, and zinc, exposed to a moist atmosphere, or placed in water holding air in solution, exhibit like phenomena. Hence the corrosion of the copper sheathing of vessels by sea-water. Hence, too, the frequent contamination of well and spring water by the leaden pipes employed in conveying it. In both cases, the first step in the series of transformations which occur, is the union of the metal with the oxygen dissolved in the water. Silver and gold, in similar circumstances, experience no change. Sulphur, and not oxygen, is the agent by which they are tarnished.

This rapid wasting of the metals, after oxydation has once commenced, finds an analogy in the moral world. The first spot of rust is the first lapse from virtue, the first stain of vice. And as that spot of rust, if not promptly removed, enlarges and spreads until it soon covers the whole surface of the metal; so that first act of vice, if not speedily repented of, becomes a habit by repetition, which continues to grow and strengthen until at length it extends its blighting influence over the entire character. But though there be this resemblance in the commencement and progress of the two cases, there is a wide difference in the results. In the first instance it is only the corrosion of a comparatively worthless price of metal; in the second, it is the wasting, the blackening, the ruin of a human soul.

The alterations which organic bodies undergo, when no longer pervaded by the principle of life, are due to the attacks of oxygen, directed still through the medium of water. In themselves they have no tendency to change. The first movement among their atoms is always impressed from without. It is the interposition of new affinities that breaks up the existing combinations and determines a rearrangement of the particles. The most delicate viands, hermetically sealed in canisters from which the air has been removed, may go round the world unaltered. Fruits hermetically sealed in their skins are in like manner preserved from decay. When the skin is broken or has become so changed in texture as to admit the air, decay at once commences. Timber sunk in mud or water to so great a depth as to be beyond the reach of oxygen, will remain unchanged for centuries. The preservative powers of alcohol do not depend simply upon its coagulating the albuminous constituents of the animal and vegetable tissues, and depriving them of a portion of their water; it shields the substances buried in it from the attacks of oxygen. Phosphorus, which soon blackens in water from superficial oxydation, undergoes no change in alcohol. In water the protoxide of iron soon runs into the peroxide. In alcohol, it remains unaltered. Turpentine and most of the essential oils owe their preservative qualities in a great measure to the exclusion of oxygen. The salts, bitumen, and aromatic gums employed by the ancient Egyptians in embalming, were not simply of service in drying and hardening the animal tissues—their chief use was in shutting out the oxygen. Whatever does this renders the bodies most liable to decay incorruptible.

As in the case of the metals, the thinner the stratum of the water interposed between organic substances and the surrounding atmosphere, the more rapidly is the oxygen transferred to them. Hence wood, hay, straw, and the fibres of cotton decay faster if simply wetted, than if wholly immersed in water. Some of these when in large quantities and pervaded by a due degree of moisture, become so heated in the interior of the mass as to pass from the ordinary to the extraordinary mode of oxydation, thus furnishing an instance of what is called spontaneous combustion. Vegetable mould and the organic constituents of manures decompose more rapidly in a sandy soil which allows the water to percolate it freely, than in a clayey soil which retains the water. One of the chief benefits of drainage consists in the freer admission of the air to all parts of the soil. The organic matters contained in it are more rapidly oxydized and converted into food for plants. If to alcohol, so far diluted as to admit the air among its particles, there be added some vegetable ferment, it will pass, by oxydation, into acetic acid and water. Many weeks, or even months, however, may be required for completing the transformation. But if the same mixed fluid be brought in contact with the air in thin laminæ, as by causing it to trickle slowly through a perforated cask filled with wood shavings, a few hours will be found sufficient to effect perfectly its oxydation.

The tendency of bodies to unite with oxygen is greatly increased if the product of their union be capable of acting as a base by the presence of an acid; or if it be capable of acting as an acid, by the presence of a base. Thus iron, copper, lead, and tin, corrode much faster in acidulated than in pure water. Even the small quantity of carbonic acid always present in rain and spring water materially facilitates the oxydation of the metals immersed in them. There is superadded to the affinity of the metals for the oxygen that of their oxides for the acid; and if the resultant salt chance to be soluble, their surface is kept constantly fresh for the corrosive action. The oxydation of lead by water becomes a source of contamination only when there is an acid present to unite with the oxide formed, and render it soluble. The wasting of the copper sheathing of vessels by sea-water is due not merely to the oxygen, but to the contained salts with which the copper, either as an oxide or as a carbonate, enters into reactions.

The arts avail themselves of this principle in the manufacture of salts. The sulphate of copper is formed by the repeated immersion of sheets of the metal in sulphuric acid so far diluted with water as to give it the power of absorbing oxygen. The same metal exposed to the combined influence of air, water, and acetic acid, passes into an acetate. Lead, under like circumstances, is converted into an acetate; or, if the proper conditions be secured, the acetic acid as well as the lead suffers oxydation, and a carbonate is produced. It is in this way that white lead is ordinarily manufactured.

If the body uniting with oxygen form an acid, the combination will be facilitated by the presence of a base. This fact explains why the decay of organic substances is hastened by lime, potash, or soda. There is superadded to their affinity for oxygen, the affinity of these powerful bases for the products of their oxydation. Even gold and platinum, if heated in the air, in contact with either of the alkalies, suffer oxydation. Nitrogen, though ordinarily manifesting so little affinity for oxygen, spontaneously unites with it when the two gases are dissolved in water and brought together in the presence of an alkali or an alkaline earth. It is probably in this manner that the nitrates, natural as well as artificial, are for the most part formed.

As oxygen and water, the medium through which it is presented, are both universally diffused, bodies have a constant tendency to unite with it, and if left to themselves, do in fact, sooner or later, pass to the state of oxides. This is their natural or statical condition; and although they may be temporarily reclaimed, they cannot be prevented from ultimately reverting to it. Metals find their way back to the state of ores from which they have been brought. The bodies of animals and plants, so long as life continues, are, indeed, exempt from the attacks of oxygen; but no sooner does life cease than they are laid hold of by this universal, omnipresent element, and fast converted into the substances from which they were formed. The work of their demolition is assisted by innumerable insects, which, pursuing them at all points, allow the destroyer freer access to every part of their tissues.

Were it not for this dissolving agency of oxygen, the earth would be everywhere strewn with the undecaying remains of plants and animals. These, accumulating generation after generation, would encumber its surface, until at length it would become one great charnel-house filled with the unburied dead.

Oxygen thus performs the part of an undertaker. It removes the dead out of our sight. And as in the case of the human undertaker, the graves to which it consigns the lifeless forms intrusted to it, are not eternal. They, too, give up their dead. The elements of the decaying tree, plant and animal, although for a time lost to our sight, at length reappear in new organic forms, clothed with fresh life and beauty.

Of the same nature is the office performed by oxygen in respiration. Penetrating with the blood all parts of the body, it passes by the living, but everywhere attacks the dead cells and prepares them for removal from the system. It is only by oxydation that the material of these cells becomes soluble, and it is only in a state of solution that they can be borne out of the living organism. Every breath is freighted with exhalations from the funeral pyres of unnumbered corpses.

In this oxydation of tissue, which is constantly going forward, certain imponderable agents or forces indispensable to the living functions are liberated. In every part of the body heat is evolved, and in the brain, that more subtle fluid, which directed along the different nervous channels, controls the movements of the entire frame. The true source of animal motive power is not to be sought in the endowments of spirit. This merely directs, it does not originate it. Volition is the touch of the key by the operator of the telegraph. Unless supplied with the requisite force by the brain, the will might as easily create an arm as move it. As in the steam-engine and the electro-magnetic engine, so in the animal organism oxydation is the true source of the power generated.

The nitrogen of the atmosphere is a mere diluent of the oxygen. It takes no part in any of the work performed by the latter. Nay, it stands in the way of the latter, and by its physical presence hinders its activities. This is, indeed, its intended office and function. Did oxygen compose the entire atmosphere, bodies coming in contact with it at points five times more numerous than they now do, would waste away too rapidly under its action. By the interposition of the nitrogen its activities are kept within the proper limits, while at the same time the atmosphere has the weight and density necessary for its mechanical functions.

Those oxydizing processes so universally in progress would soon cease from the exhaustion of subjects, were there no provisions in nature for their continued supply. Such provisions, however, are found in the vegetable organism. In the leaves of plants while under the influence of the sun's rays, water and carbonic acid, the sulphates and the phosphates, undergo re-solution. The greater part of the oxygen is thrown off, while the hydrogen, carbon, sulphur, and phosphorus are wrought into the vegetable tissues. The vast bodies of bituminous and anthracite coal occurring in different parts of the earth, were once floating in the atmosphere in the form of carbonic acid and water, and it is only by passing through the organisms of plants that they have been brought to their present state. The food of animals has all been, in like manner, deoxydized. Indeed the leaf of the plant may be regarded as an apparatus specially designed for the application of the solar beam to the reduction of carbon, hydrogen, sulphur, &c., from the state of oxides. It is only the rays of the sun that can effect this, and the rays of the sun are capable of effecting it only in the leaf of the plant. Hence the interposition of the vegetable between the mineral and the animal kingdoms. Even where man would effect the reduction of any of the metals from their ores, he is obliged to resort to some substance which has been deoxydized by the solar beam in the leaf of the plant.

All deoxydized bodies, therefore, whatever their immediate origin, are representations of sun power. Sun power has actually been exerted, either directly or indirectly, in their production. And when they revert to the state of oxides, there is an evolution of force equal in amount to that which was expended in their isolation. Hence the real source of steam-power, of electro-magnetic power, and of animal motive power. All of those in the last analysis resolve themselves into sun power, directed through the mechanism of the vegetable cell to the re-solution of oxides.

We have thus far contemplated oxygen as a dissolving agent. We have seen that it literally goes about seeking what it may destroy. Although respecting the living, and passing by them unharmed, it everywhere attacks the organic forms from which life has departed and quickly resolves them into the elements from which they were formed.

But oxygen is not simply a destroying agent. It takes to pieces the bodies of the dead only that it may find materials for repairing and building up those of the living. The hydrogen and the carbon which it gathers from the decaying wood or the mouldering dust, it conveys into the leaf of the growing plant. Having there deposited its burden, it issues again and recommences its wanderings in search of a new one to have a like destination. Could we *see* oxygen, could we make it visible not only to the mind's eye, but to the eye of sense, as it speeds on its beneficent mission, we might then observe two little winged atoms floating along upon the buoyant air, until at length lighting upon some decaying matter, they lay hold of an atom of carbon, and taking it up as the two shining ones on the farther side of the river took up Bunyan's pilgrim, bear it away, not to the golden city, but up among the green leaves and beautiful flowers, there to minister to and have part in their verdure and beauty. In observing this, we should recognise oxygen in its most characteristic and habitual office of carrier between the dead and the living. Indeed, at every point of that great cycle through which life and death move hand in hand, the activity of this element is most conspicuous. While by an irreversible law, inscrutable as it is irreversible, life in our world everywhere terminates in death; through the appointed instrumentality of this agent, new life as constantly springs from its ashes.

Oxygen, therefore, performs the office of restorer as well as destroyer. It is the Vishnu as well as Siva of the Hindoo triad, and, in nature, its action in both capacities is a beneficent one.

On the products of man's labor, however, its agency is less kindly. These, so far as they consist of materials capable of entering into union with it, gradually waste away under its influence, like the dead forms of plants and animals. Iron, subserving so many and so important uses, entering so largely not only into the construction of the tools and implements of the mechanic arts, but into the products of these arts—iron, exposed to the combined influence of air and water, quickly begins to corrode, and, in spite of its strong bands of cohesion, soon crumbles into dust. Implements and structures of brass are scarcely more enduring. Wood, and everything formed of it or reared from it, yield to the same law of decay. "Dust thou art, and unto dust thou shalt return," is written not only of man himself, but of all, even the most enduring of his works. Even in that strange land where the finger of time touches with such marvellous lightness, the most strenuous and persevering efforts to resist this law of decay have proved unavailing. The pyramid and the obelisk crumble, while "Miriam cures wounds and Pharaoh is sold for balsam." Man's only hope of immortality must come from his higher, his spiritual nature; that acknowledges not corruption as its father; that is unchanging, exempt from all touch of decay, immortal, eternal, like the Great Being in whose image it was formed. But it is a law of all material, all earthy, all sublunary things, to change, moulder, decay, pass away; and the great principle, or agent, or instrument of this decay, this dissolution, is oxygen, whose office and ministry in nature we have this evening been contemplating.

LECTURE

ON METEORIC STONES.

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The class of bodies which form the subject of this lecture are those solid masses which, from time to time, are seen to fall from the heavens to the earth, and bear the name of meteorites, meteoric stones, or aëriolites, the former not being as appropriate a name as the two last. They are divided into two great classes, *stony and metallic*, which in their turn may be subdivided. The fall of the former is much more frequent than that of the latter, amounting to ninety-six per cent. of those discovered.

The masses before you are beautiful specimens of the metallic variety. One of them was found near Tazewell, Claiborne county, Tennessee; the second, in Campbell county of the same State; and the third, in Coahuila, Mexico. The following is their history and description:

Fig. 1.

1. *The meteoric iron from Tazewell, Tennessee* (Fig. 1).—This meteorite was not observed to fall, but was found in August, 1853, it doubtless having fallen at a period very much earlier than that of its discovery. The weight of this meteorite was fifty-five pounds. It is of a flattened shape, with numerous conchoidal indentations, and three annular openings passing through the thickness of the mass near the outer edge. Two or three places on the surface are flattened, as if other portions were attached at one time, but had been rusted off by a pro-

cess of oxydation that has made several fissures in the mass, so as to allow portions to be detached by the hammer, although when the metal is sound the smallest fragment could not be thus separated, it being both hard and tough. Its dimensions are such that it will just lie in a box 13 inches long, 11 inches broad, and 5½ inches deep.

The exterior is covered with oxyd of iron, in some places so thin as hardly to conceal the metal, in other places a quarter of an inch deep. Its hardness is so great that it is almost impossible to detach portions by means of a saw. Its color is white, owing to the large amount of nickel present; and a polished surface when acted on by hot nitric acid displays in a most beautifully regular manner the Widmannstättian figures. The specific gravity of three fragments selected for their compactness and purity, was from 7.88 to 7.91.

The following minerals have been found to constitute this meteorite: 1st. *Nickeliferous iron*, forming nearly the entire mass. 2d. *Protosulphuret of iron*, found in no inconsiderable quantity on several parts of the exterior of the mass. 3d. *Schreibersite*, found more or less mixed with the pyrites and in the crevices of the iron, in pieces from the thickness of the blade of a penknife to that of the minutest particles. 4th. *Olivine;* two or three very small pieces of this mineral have been found in the interior of the iron. 5th. *Protochlorid of iron;* this mineral has been found in this meteorite *in the solid state*, which I believe is the first observation of this fact; it was found in a crevice that had been opened by a sledge hammer, and in the same crevice Schreibersite was found. Chloride of iron is also found deliquescing on the surface; some portions of which, however, are entirely free from it, while others again are covered with an abundance of rust arising from its decomposition.

Besides the above minerals, two others were found—one a silicious mineral, the other in minute rounded black particles; both, however, were in too small quantity for anything like a correct idea to be formed of their composition.

The analyses of the metallic portion furnished in two specimens were as follows:

	No. 1.	No. 2.
Iron	82.39	83.02
Nickel	15.02	14.62
Cobalt	.43	.50
Copper	.09	.06
Phosphorus	.16	.19
Chlorine		.02
Sulphur		.08
Silica	.46	.84
Magnesia		.24
	98.55	99.57

Tin and arsenic were looked for, but neither of those substances were detected.

The composition of the nickeliferous iron corresponds to five atoms of iron and one of nickel.

Iron......	5 atoms	82.59
Nickel...	1 atom	17.41=100.00

Schreibersite is found disseminated in small particles through the mass of the iron, and is made evident by the action of hydrochloric acid; it is also detected in flakes of little size, inserted as it were into the iron; and owing to the fact that in many parts where it occurs, chloride of iron also exists; this last has caused the iron to rust in crevices, and on opening these, Schreibersite was detached mechanically. This mineral as it exists in the meteorite in question, so closely resembles magnetic pyrites that it can be readily mistaken for this latter substance, and I feel confident in asserting that a great deal of the so-called magnetic pyrites associated with various masses of meteoric iron, will, upon examination, be found not to contain a trace of sulphur, and will, on the contrary, prove to be Schreibersite that can be easily recognised by its characters.

Its color is yellow or yellowish white, sometimes with a greenish tinge; lustre metallic; hardness 6; specific gravity 7.017. No regular crystalline form was detected; its fracture in one direction is conchoidal. It is attracted very readily by the magnet, even more so than magnetic oxyd of iron; it acquires polarity and retains it. I have a piece $\frac{8}{10}$ of an inch long, $\frac{2}{10}$ of an inch broad, and $\frac{1}{20}$ of an inch thick, which has retained its polarity over six months; unfortunately the polarity was not tested immediately when it was detached from the iron, and not until it had come in contact with a magnet, so that it cannot be pronounced as originally polar.

Three specimens of the Schreibersite were examined, and gave results as follows:

	1.	2.	3.
Iron	57.22	56.04	56.53
Nickel	25.82	26.43	28.02
Cobalt	0.32	0.41	0.28
Copper	*trace*	not estimated.	
Phosphorus	13.92		14.86
Silica	1.62		
Alumina	1.63		
Zinc	*trace*	not estimated.	
Chlorine	0.13		
	100.66		99.69

The formula of Schreibersite, I consider to be Ni_2Fe_4P.

		Per cent.
Phosphorus	1 atom	15.47
Nickel	2 "	29.17
Iron	4 "	55.36

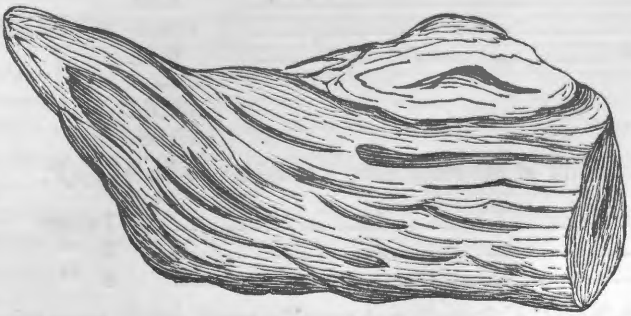
This mineral, although not usually much dwelt upon when speaking of meteorites, is decidedly the most interesting one associated with this class of bodies, even more so than the nickeliferous iron. In breaking open one of the fissures of this Tazewell meteorite, a small amount of a green substance was obtained that was easily soluble in water, and although not analyzed quantitatively, it left no doubt upon my mind as to its being protochlorid of iron; and the manner of its occurrence gave strong evidence of its being an original constituent, and not formed since the fall of the mass. Chloride of iron was apparent on various parts of the iron, by its deliquescence on the surface.

2. *The meteoric iron from Campbell county, Tennessee.*—This meteorite was discovered in July, 1853, in Campbell county, in Stinking creek, which flows down one of the narrow valleys of the Cumberland mountains, by a Mr. Arnold, and was presented to me by Professor Mitchell, of Knoxville. It is of an oval form, 2¼ inches long, 1¾ broad, and ¾ thick, with an irregular surface and several cavities perforating the mass. It was covered with a thin coat of oxyd; and on one-half of it chloride of iron was deliquescing from the surface, while on another portion there was a thin silicious coating. The iron was quite tough, highly crystalline, and exhibited small cavities on being broken, resembling very much in this respect, as well as in many other points, the Hommony creek iron; a polished surface when etched, exhibited distinct irregular Widmannstättian figures. The weight is 4⅓ ounces. Specific gravity, 7.05. The lowness of the specific gravity is accounted for by its porous nature. The composition is as follows:

Iron	97.54
Nickel	0.25
Cobalt	0.6
Copper, too small to be estimated.	
Carbon	1.50
Phosphorus	0.12
Silica	1.05
	100.52

Chlorine exists in some parts in minute proportion. The amount of nickel, it will be seen, is quite small, but its composition is, nevertheless, perfectly characteristic of its origin.

Fig. 2.



3. *The meteoric iron from Coahuila, Mexico* (Fig. 2.)—This meteorite, now in the collection of the Smithsonian Institution, was brought to this country by Lieutenant Couch, of the United States army, he having obtained it at Saltillo. It was said to have come from the San-

cha estate, some fifty or sixty miles from Santa Rosa, in the north of Coahuila; various accounts were given of the precise locality, but none seemed very satisfactory. When first seen by Lieutenant Couch, it was used as an anvil, and had been originally intended for the Society of Geography and Statistics in the city of Mexico. It is said, that where this mass was found there are many others of enormous size; but such stories, however, are to be received with many allowances. Mr. Weidner, of the mines of Freiberg, states, that near the southwestern edge of the Balson de Mapimi, on the route to the mines of Parral, there is a meteorite near the road of not less than a ton weight. Lieutenant Couch also states, that the intelligent, but almost unknown, Dr. Berlandier writes, in his journal of the Commission of Limits, that at the Hacienda of Venagas, there was (1827) a piece of iron that would make a cylinder one yard in length, with a diameter of ten inches. It was said to have been brought from the mountains near the Hacienda. It presented no crystalline structure, and was quite ductile.

The meteorite now before you (see Fig. 2) weighs 252 pounds, and from several flattened places I am led to suppose that pieces have been detached. The surface, although irregular in some places, is rather smooth, with only here and there thin coatings of rust, and, as might be expected, but very feeble evidence of chlorine, and that only on one or two spots. The specific gravity is 7.81. It is highly crystalline, quite malleable, and not difficult to cut with the saw. Its surface etched with nitric acid, presents the Widmannstättian figures, finely specked between the lines, resembling the representation we have of the etched surface of Hauptmannsdorf iron. Schreibersite is visible, but so inserted in the mass, that it cannot be readily detected by mechanical means. Hydrochloric acid leaves a residue of beautifully brilliant patches of this mineral.

Subjected to analysis, it was found to contain

Iron	95.82
Cobalt	0.35
Nickel	3.18
Copper, minute quantity, not estimated.	
Phosphorus	0.24
	99.59

Which corresponds to

Nickeliferous iron	98.45
Schreibersite	1.55
	100.00

The iron is remarkably free from other constituents.

The specimen is especially interesting as the largest mass of meteoric iron in this country next to the Texas meteorite at Yale College.

The three meteorites just described form an interesting addition to those already known, a very complete list of which has been lately made by Mr. R. P. Greg, jr., to which I would refer all those specially interested in this subject. It is to be found in the Lond. Phil. Mag. for 1854.

A fact of much interest is that the number of meteorites already discovered in the United States is quite large, and, contrary to the general rule, the iron masses are the most numerous. The following table, by Mr. Greg, jr., shows at a glance the number of meteorites already found in different countries, the proportions of the stones and irons, and the average latitude of their localities.

Countries.	Stones.	Irons.	Total.	Average latitude. °
United States	19	36	55	35 N.
Bavaria, Prussia, Germany	38	6	44	51 N.
France	34	1	35	46 N.
Lombardy, Piedmont, Sicily, Italy	33	1	34	43 N.
Hungary, Bohemia, Austria	28	5	33	48 N.
Japan, China	23		23	18 N.
Ceylon and India	19	3	22	20 N.
Ireland and Great Britain	20	1	21	53 N.
European Russia	14	1	15	54 N.
West Indies and Mexico	2	10	12	25 N.
Asia Minor, Crète, Turkey	10	1	11	40 N.
Portugal and Spain	9		9	40 N.
South America	1	8	9	20 S.
Finland and Siberia	4	3	7	63 N.
Egypt, Arabia, and North Africa	6	1	7	30 N.
South Africa	2	2	4	30 S.
Tartary, Persia, and Central Asia	1	2	3	35 N.
Greenland	1	2	3	65 N.
Switzerland	2		2	46 N.
Sweden	1		1	60 N.
Sandwich Islands	1		1	20 N.
Java	1		1	10 S.
Canada		1	1	

The number of these bodies which fall annually cannot be well determined. In the last sixty years the average falls *observed* are ten per annum; but of course the actual number must have far exceeded this, and some authors have supposed that not less than five hundred must fall annually on various parts of the surface of the globe.

In this lecture our object is not to enter into a detailed account of all the peculiarities of appearance of meteoric stones, either while falling or after their descent. The more immediate object is to consider the probable origin of these bodies; yet it is of general interest to mention some of those peculiarities before proceeding to the theoretical discussion.

Meteoric stones, as they fall, frequently exhibit light; are sometimes accompanied by a noise, and occasionally burst into several fragments. All of these phenomena are produced after they enter our atmosphere, which they do at a very great velocity; heat is developed in them by their friction against the air; the iron they contain is subject to combustion, which is augmented by the condensed condition of the atmosphere before the object while in rapid motion. All this suffices for the production of the light exhibited. Light does not always accompany the fall of these bodies—a fact which, it is reasonable to suppose, belongs especially to the masses of iron, which, from the compact nature of their structure, and their great conductibility, cannot become so readily heated on the surface as to reach the point of incandescence. The noise is produced by their rapid motion through the air, and their bursting by the combined effects of irregular expansion by heat, and certrifugal force produced by irregular resistance of the atmosphere; the latter being alone sufficient to bring about such a result, as is shown by the shooting of stone balls from a cannon. The velocity of these bodies will be discussed in another part of this lecture.

The lessons to be learned from meteorites, both stony and metallic, are probably not as much appreciated as they ought to be; we are usually satisfied with an analysis of them and surmises as to their origin, without due consideration of their physical and chemical characteristics.

The great end of science is to deduce general principles from particular facts. Thus terrestrial gravitation has been extended to the whole solar system, and, indeed, to the whole visible universe. The astronomer, however, has only proved the universality of this one law, and has found no evidence that any other force observed at the surface of the earth displays itself in any other sphere. However probable it may appear that the same laws affect terrestrial and celestial matter, it is none the less interesting to extend our proofs of this assumption, and meteorites, when looked upon in this light, acquire additional interest.

First. They lead us to the inference that the materials of the earth are exact representatives of those of our system, for up to the present time no element has been found in a meteorite that has not its counterpart on the earth; or if we are not warranted in making such a broad assumption, we certainly have the proof, as far as we may ever expect to get it, that some materials of other portions of the universe are identical with those of our earth.

Second. They show that the *laws of crystallization* in bodies foreign to the earth are the same as those affecting terrestrial matter, and in this connexion we may instance pyroxene, olivine and chrome iron, affording, in their chrystalline form, angles identical with those of terrestrial origin.

Third. The most interesting fact developed by meteorites is the universality of the laws of chemical affinity, or the truth, that the laws of chemical combination and atomic constitution are to be equally well seen in extra-terrestrial and terrestrial matter; so that were Dalton or Berzelius to seek for the atomic weights of iron, silica or magnesia, they might learn them as well from meteoric minerals as from those taken from the bowels of the earth. The atomic constitution of meteoric anorthite, or of pyroxene, is the same as of that which exists in our own rocks.

An important peculiarity of the stony meteorites is, that their outer surface is covered with a coating strongly resembling pitch; this is a species of glass formed from the heated condition to which the meteorite arrives in its passage through the air, the heat acquired being sufficient to fuse the outer surface. The black color is due to the protoxide of iron combining with the silica. In most instances the protoxide is formed from the oxydation of the particles of metallic iron in the mass.

Keeping in view then the physical and chemical characters of meteorites, I propose to offer some theoretical considerations which, to be fully appreciated, must be followed step by step. These views are not offered because they individually possess particular novelty; it is the manner in which they are combined to which especial attention is called.

The first *physical characteristic* to be noted is their form. No masses of rock, however rudely detached from a quarry, or blasted from the side of a mountain, or ejected from the mouth of a volcano, would present more diversity of form than meteoric stones; they are rounded, cubical, oblong, jagged, and flattened. Now, the fact of form I conceive to be a most important point for consideration in regard to the origin of these bodies, as this alone is strong proof that the individual meteorites have not always been cosmical bodies; for had this been the case, their form must have been spherical or spheroidal. As this is not so, it is reasonable to suppose that at one time or another they must have constituted a part of some larger mass. But, as this subject will be taken up again, I pass to another point—namely, the crystalline structure; more especially that of the iron, and the complete separation in nodules, in the interior of the iron, of sulphuret and phosphuret of the metals constituting the mass. When this is properly examined, it is seen that these bodies must have been in a plastic state for a great length of time, for nothing else could have determined such crystallization as we see in the iron, and allow such perfect separation of sulphur and phosphorus from the great bulk of the metal, combining only with a limited portion to form particular minerals. No other agent than fire can be conceived of by which this metal could be kept in the condition requisite for the separation. If these facts be admitted, the natural inference is that they could only have been thus heated while a part of some large body.

Another physical fact worthy of being noticed here, is the manner in which the metallic iron and stony parts are often interlaced and mixed, as in the Pallas and Atacama specimens, where nickeliferous iron and olivine in nearly equal portions (by bulk) are intimately mixed, so that when the olivine is detached, the iron resembles a very coarse sponge. This is an additional fact in proof of the great heat to which the meteorites must have been submitted; for, with our present knowledge of physical laws, there is no other way in which we can conceive that such a mixture could have been produced. Other physical points might be noticed; but as they would add nothing to the theoretical considerations, they will be passed over.

The *mineralogical and chemical points to be noted in meteorites* are as follows: The rocks or minerals of these bodies are not of a sedimentary character, nor such as are produced by the action of water. This is obvious to any one who will examine them. A mineralogist will also be struck with the thin dark-colored coating on the surface of the stony meteorites; but this is in most, if not in all instances, the product of our atmosphere, and need not be further noticed. A more interesting peculiarity is that metallic iron, alloyed with nickel and cobalt, is of constant occurrence in meteorites, with but three or four exceptions—in some instances constituting the entire mass, at other times disseminated in fine particles through stony matter. The existence of this highly oxydizable mineral in its metallic condition is a positive indication of a scarcity, or total absence, of oxygen (in its gaseous state, or in the form of water) in the locality from whence the body came.

Another mineralogical character of significance is, that the stony portions of the meteorites resemble the older igneous rocks, and particularly the volcanic rocks belonging to various active and extinct volcanoes. It is useless to dwell on this fact; the inference to be drawn from it is very evident. It is highly significative of the igneous origin of these bodies, and of an igneous action in other portions of space similar to that now existing in our volcanoes.

Ever since the labors of Howard in 1802, *the chemical constitution of meteorites* has attracted much attention, more especially the elements associated in the metallic portion; and although we find no new elements, still their association, so far as yet known, is peculiar to this class of bodies. Thus nickel is a constant associate of iron in meteorites, (if we except the Walker county, Alabama, and Oswego, New York, meteorites, upon whose claims to meteoric origin there yet remains some doubt;) and although cobalt and copper are mentioned only as occasional associates, in my examination of nearly thirty known specimens (in more than one-half of which these constituents were not mentioned) I have found both of the last-mentioned metals as constantly as the nickel. With our more recent method of separating cobalt from nickel, very accurate and precise results can be obtained relative to the former. The copper exists always in such minute proportion, that the most careful manipulation is required to separate it.

Another element frequently, but not always, occurring in association with the iron is phosphorus. Here again an examination of thirty specimens of this substance leads me to a similar generalization, namely, that no meteoric iron is to be expected without it; my examination has extended as well to the metallic particles separated from the stony meteorites as to the meteoric irons proper. It may be even further stated, that, in most instances, the phosphorus was traceable directly to the mineral Schreibersite.

These four elements, then, (iron, nickel, cobalt, and phosphorus,) I consider remarkably constant ingredients: first, in the meteoric irons proper; and secondly, in the metallic particles of the stony meteorites; there being only some three or four meteorites, among hundreds that are known, in which they are not recognised.

As regards the combination of these elements, it is worthy of remark that no one of them is associated with oxygen, although all of them have a strong affinity for this element, and are never found (except copper) in the earth uncombined with it, except where some similar element (as sulphur, &c.) supplies its place.

The inference of the absence of oxygen in a gaseous condition, or in water, is drawn from such substances as iron and nickel being in their metallic state, as has been just mentioned ; but it must not be inferred that oxygen is absent in all forms at the place of origin of the meteorites, for the silica, magnesia, protoxyd of iron, &c., contain this element. The occurrence of one class of oxyds and not of another would indicate a limited supply of the element oxygen, the more oxydizable elements, as silicon, magnesium, &c., having appropriated it in preference to the iron.

Many other elements worthy of notice might be mentioned here, and some of them, for aught we know, may be constant ingredients ; but in the absence of strong presumption, at least, on this head, they will be passed over, as those already mentioned suffice for the support of the theoretical views to be advanced.

I cannot, however, avoid calling attention to the presence of *carbon* in certain meteorites ; for although its existence is denied by some chemists, it is nevertheless a fact that can be as easily established as the presence of the nickel. The interest to be attached to it is due to the fact that it is so commonly regarded in the light of an organic element. It serves to strengthen the notion that carbon can be of pure mineral origin, for no one would be likely to suppose that the carbon found its way into a meteorite, either directly or indirectly, from an organic source.

Having thus noted the predominant physical, mineralogical, and chemical characteristics of meteorites, I pass on to the next head.

Marked points of similarity in the constitution of meteoric stones.— Had this class of bodies not possessed certain properties distinguishing them from terrestrial minerals, much doubt would even now be entertained of their celestial origin, even in those cases where the bodies were seen to fall. But chemistry has entirely dissipated all doubts on this point, and now an examination in the laboratory is entitled to more credit than evidence from any other source in pronouncing on the meteoric origin of a body. When the mineralogical and chemical compositions of these bodies are regarded, the most ordinary observer will be struck with the wonderful family likeness presented by them all.

There are three great divisions of meteoric bodies, namely: metallic; stony, with small particles of metal ; and a mixture of metallic and stony in which the former predominates, as in the Pallas and Atacama meteorites. The external appearances of these three classes differ in a very marked manner ; the *meteoric iron* being ordinarily of a compact structure, more or less corroded externally, and, when cut, showing a dense structure with most of the peculiarities of pure iron, only a little harder and whiter. The *stony meteorites* are usually of a grey or greenish grey color, granular structure, readily broken by a blow of the hammer, and exteriorly are covered with a thin coating of fused material. The *mixed meteorite* presents characters of both of the above; a large portion of it consists of the kind of iron already mentioned, cellular in its character, and the spaces filled up with stony materials, similar in appearance to those constituting the second class.

Although there are some instances of bodies of undoubted meteoric origin not properly falling under either of the above heads, still they will be seen, upon close investigation, not to interfere in any way with the general conclusions that are attempted to be arrived at; for these constituents are represented in the stony materials of the second class, from which their only essential difference consists in the absence of metallic particles.

If we now examine chemically the three classes mentioned, we find them all possessed of certain common characteristics that link them together, and at the same time separate them from everything terrestrial. Take first the metallic masses; and in very many instances, in some fissure or cavity, exposed by sawing or otherwise, stony materials will frequently be found, and a stony crystal is sometimes exposed: now examine the composition of these, and then compare the results with what may be known of the stony meteorites, and in every instance it will agree with some mineral or minerals found in this latter class, as olivine or pyroxene, most commonly the former; but in no instance is it a mineral not found in the stony meteorites. If these last, in their turn, be examined, differing vastly in their appearance from the metallic meteorites, they will, with but two or three exceptions, be found to contain a malleable metal identical in composition with the metal constituting the metallic meteorites.

As to the mixed meteorites in which the metallic and stony portions seem to be equally distributed, their two elements are but representatives of the two classes just described. Examined in this way, there will be no difficulty in tracing their connexion.

There is one mineral which there is every reason to believe constantly accompanies the metallic portions, and which may be regarded as a most peculiar mark of difference between meteorites and terrestrial bodies. It is the mineral *Schreibersite*, (mentioned in the first part of this lecture,) to which the constant presence of phosphorus in meteoric iron is due. This mineral, as already remarked, has no parallel on the face of the globe, whether we consider its specific or generic character; there being no such thing as phosphuret of iron and nickel, or any other phosphuret, found among minerals. These facts render the consideration of Schreibersite one of much interest, running, as it probably does, through all meteorites, and forming another point of difference between meteorites and terrestrial objects.

Another striking similarity in the composition of meteorites is the limited action of oxygen on them. In the case of the purely metallic meteorites we trace an almost total absence of this element. In the stony meteorites the oxygen is in combination with silicon, magnesium, &c., forming silica, magnesia, &c., that combine with small portions of other substances to form the predominant earthy minerals of meteorites; and when iron is found in combination with oxygen, it occurs in its lowest state of oxydation, as in the protoxyd of the olivine and chrome iron, and as magnetic oxyd.

Without going further into detail as regards the similarity of composition of meteorites, they will be seen to have as strongly marked points of resemblance as minerals coming from the same mountain, I might almost say from the same mine; and it is not asking much to admit their having a *common centre of origin*, and that whatever may be the body from which they originate, it must contain no uncombined oxygen, and, I might even add, none in the form of water.

I shall now speak of the *origin of meteoric stones.* In taking up the theoretical considerations of the subject of the lecture, it is of the utmost consequence not to consider shooting stars and meteoric stones as all belonging to the same class of bodies—a view entertained by many distinguished observers. It is doubtless less owing to the fact of their having been confounded, that there exists such a difference of opinion as to the origin of these bodies.

It may be considered a broad assumption that there is not a single evidence of the identity of shooting stars and the meteors which give rise to meteoric stones; but this conclusion is one arrived at by as full an examination of the subject as I am capable of making.* Some of the prominent reasons for such a conclusion will be mentioned.

Were shooting stars and meteoric stones the same class of bodies, we might expect that the fall of the latter would be most abundant when the former are most numerous. In other words, the periodic occurrences of shooting stars in August and November, and more particularly the immense meteoric showers that are sometimes seen, ought to be attended with the fall of meteoric stones; whereas there is not a single occurrence of this kind on record. Again: in all instances where a meteoric body has been seen to fall, and has been observed even from its very commencement, it has been alone, and not accompanied by other meteors.

Another objection to the identity of these bodies is the difference in velocity. That of the shooting stars can readily be determined by the simultaneous observations of two observers; and it has been found that their average rate of motion is about 16½ miles a second, while, in order that they should revolve around the earth through the atmosphere, their velocity must be less than six miles a second.† Now, we know that the meteors do enter our atmosphere, and probably often pass through it without falling to the earth; but as the most correct observations have never given a velocity of less than nine miles a second to a shooting star, it is reasonable to suppose that none have ever entered our atmosphere, or, what is perhaps still more probable,

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* Prof. D. Olmsted, in a most interesting article on the subject of meteors, to be found in the 26th volume of the Am. Journal of Science, p. 132, insists upon the difference between shooting stars and meteorites, and the time and attention he has devoted to the phenomena of meteors give weight to his opinion.

† Under this head, I will merely note what is considered one of the best established cases of the determination of velocity of a meteoric stone, namely, that of the Weston meteorite, the velocity of which Dr. Bowditch estimated to "*exceed three miles a second.*" Mr. Herrick considers the velocity somewhat greater, and writes, among other things, what follows: "The length of its path, from the observations made at Rutland, Vermont, and at Weston, was at least 107 miles. This space being divided by the duration of the flight, as estimated by two observers, viz., 30 seconds, we have for the meteor's relative velocity about *three and a half miles a second.* The observations made at Wenham, Massachusetts, are probably less exact in this respect, and need not be mentioned here.

that the matter of which they are composed is as subtle as that of Encke's comet, and any contact with even the uppermost limit of the atmosphere destroys their velocity and disperses the matter of which they are composed.

Other grounds might be mentioned for supposing a difference between shooting stars and meteoric stones, and I have dwelt on it thus much because it is conceived of prime importance in pursuing the correct path that is to lead to the discovery of their origin.

Various theories have been devised to account for the origin of the meteorites. One is that they are small planetary bodies revolving around the sun, and at times become entangled in our atmosphere, lose their orbital velocity by the resistance of the air, and fall finally to the earth; another supposes them to have been ejected from volcanoes of the moon; and lastly, they are considered as formed from particles floating in the atmosphere. The exact nature of this last theory is given by Professor C. U. Shepard, in an interesting report on meteorites published in 1848. He* says: "The extra-terrestrial origin of meteoric stones and iron masses seems likely to be more and more called in question with the advance of knowledge respecting such substances, and as additions continue to be made to the connected sciences. Great electrical excitation is known to accompany volcanic eruptions, which may reasonably be supposed to occasion some chemical changes in the volcanic ashes ejected; these being wafted by the ascensional force of the eruption into the regions of the magneto-polar influence, may there undergo a species of magnetic analysis. The most highly magnetic elements, (iron, nickel, cobalt, chromium, &c.,) or compounds in which these predominate, would thereby be separated and become suspended in the form of metallic dust, forming those columnar clouds so often illuminated in auroral displays, and whose position conforms to the direction of the dipping needle. While certain of the diamagnetic elements, (or combinations of them,) on the other hand, may, under the control of the same force, be collected into different masses, taking up a position at right angles to the former, (which Faraday has shown to be the fact in respect to such bodies,) and thus produce those more or less regular arches, transverse to the magnetic meridian, that are often recognised in the phenomena of the aurora borealis.

"Any great disturbance of the forces maintaining these clouds of meteor-dust, like that produced by a magnetic storm, might lead to the precipitation of portions of the matter thus suspended. If the disturbance was confined to the magnetic dust, iron masses would fall; if to the diamagnetic dust, a non-ferruginous stone; if it should extend to both classes simultaneously, a blending of the two characters would ensue in the precipitate, and a rain of ordinary meteoric stones would take place.

"The occasional raining of meteorites might, therefore, on such a

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* I must, in justice to Professor Shepard, say that since this lecture was delivered he has informed me that he no longer entertains these views; and I would now omit the criticism of them did they not exist in his memoir uncontradicted, and also were they not views still entertained by some.

theory, be as much expected as the ordinary deposition of moisture from the atmosphere. The former would originate in a mechanical elevation of volcanic ashes and in matter swept into the air by tornadoes; the latter from simple evaporation. In the one case, the matter is upheld by magneto-electric force; in the other, by the law of diffusion, which regulates the blending of vapors and gases, and by temperature. A precipitation of metallic and earthy matter would happen on any reduction of the magnetic tension; one of rain, hail, or snow, on a fall of temperature. The materials of both originate in our earth. In the one instance they are elevated but to a short distance from its surface, while in the other they appear to penetrate beyond its farthest limits, and possibly to enter the inter-planetary space; in both cases, however, they are destined, through the operation of invariable laws, to return to their original repository."

This theory, or rather hypothesis, coming as it does from one who is justly entitled to high consideration, from the fact of the special attention he has given to the subject of meteorites, may mislead, and for this reason the objections which may be advanced against it ought to be stated. First, it must be proved that terrestrial volcanoes contain all the varieties of matter found in the composition of meteoric bodies. It is true that many of the substances are ejected from volcanoes, as olivine, &c., but then the principal one, nickeliferous iron, has never in a single instance been found in the lava or other matter coming from volcanoes, although frequently sought for.

But the physical obstacles are a still more insuperable difficulty in the way of adopting this theory. In the first place it is considered a physical impossibility for tornadoes or other currents of air to waft matter, however impalpable, "beyond the farthest limits of the earth, and, possibly, into interplanetary space." Again, if magnetic and diamagnetic forces cause the particles to coalesce and form solid masses, by the cessation of those forces the bodies would crumble into powder.

We pass on to a concise statement of some of the chemical objections to this theory of atmospheric origin, and, if possible, they are more insuperable than the last-mentioned. Contemplate for a moment the first meteorite described in this lecture—a mass of iron of about sixty pounds of a most solid structure, highly crystalline, composed of nickel and iron chemically united, containing in its centre a crystalline phosphuret of iron and nickel, and on its exterior surface a compound of sulphur and iron, also in atomic proportions—and can the mind be satisfied in supposing that the dust wafted from the crater of a volcano into the higher regions of the atmosphere could, *in a few moments of time*, be brought together by any known forces so as to create the body in question? However finely divided this volcanic dust might be, it can never be subdivided into atoms, a state of things that must exist to form bodies in atomic proportions, where no agency is present to dissolve or fuse the particles. One other objection and I have done with this hypothesis. The particles of iron and nickel supposed to be ejected from the volcano must pass from the heated mouth of a crater, ascend through the oxygen of the atmosphere without undergoing the slightest oxydation; for if there be any one thing which marks the meteorites more strongly than any other, it is the freedom of the masses of iron from oxydation except on the surface. But a still more remarkable abstinence from oxydation would be the ascent of the particles of phosphorus to form the Schreibersite traceable in so many meteorites.

Having noticed the prominent objections to this hypothesis, I pass on to consider, in as few words as possible, the other two suppositions.

The most generally adopted theory of the origin of meteoric bodies is that they are small planetary bodies revolving around the sun, one portion of their orbit approaching or crossing that of the earth; and from the various disturbing causes to which these small bodies must necessarily be subjected, their orbits are constantly undergoing more or less variation, until intersected by our atmosphere, when they meet with resistance and fall to the earth's surface in whole or in part; this may not occur in their first encounter of the atmosphere, but repeated obstructions in this medium at different times must ultimately bring about the result. In this theory their origin is supposed to be the same as that of other planetary bodies, and they are regarded as always having had an individual cosmical existence. Now, however reasonable the admission of this orbital motion immediately before and for some time previous to their contact with the earth, the assumption of their original cosmical origin would appear to have no support in the many characteristics of meteoric bodies as enumerated before. The form alone of these bodies is anything but what ought to be expected from a gradual condensation and consolidation; all the chemical and mineralogical characters are opposed to this supposition. If the advocates of this hypothesis do not insist on the last feature of it, then it amounts to but little else than a statement that meteoric stones fall to us from space while having an orbital motion. In order to entitle this planetary hypothesis to any weight it must be shown how bodies, formed and constructed as these are, could be other than fragments of some very much larger mass.

As to the existence of meteoric stones in space travelling in a special orbit prior to their fall, there can be but little doubt, when we consider their direction and velocity; their composition proving them to be of extra-terrestrial origin. This, however, only conducts in part to their origin, and those who examine them chemically will be convinced that the earth is not the first great mass that metoric stones have been in contact with, and this conviction is strengthened when we reflect on the strong marks of community of origin so fully dwelt upon.

It is, then, with the consideration of what was the connexion of these bodies prior to their having an independent motion of their own, that this lecture will be concluded.

It only remains to bring forward the facts already developed to exhibit the plausibility of the hypothesis of the lunar origin of meteoric stones.

It was originally proposed as early as 1660, by an Italian philosopher, Terzago, and advanced by Olbers in 1795, without any knowledge of its having been before suggested; it was sustained by Laplace, with all his mathematical skill, from the time of its adoption to his death; it was also advocated, on chemical grounds, by Berzelius, whom I have no reason to believe ever changed his views in regard to it; and to these we have to add the following distinguished mathematicians and philosophers: Biot, Brandes, Poisson, Quetelet, Arago, and Benzenberg, who have at one time or another advocated the lunar origin of meteorites.

Some of the above astronomers abandoned the theory—among them Olbers and Arago; but they did not do so from any supposed defect in it, but from adopting the assumption that shooting stars and meteorites were the same, and on studying the former and applying the phenomena attendant upon them to meteorites, the supposed lunar origin was no longer possible.

On referring to the able researches of Sears C. Walker on the periodical meteors of August and November, (Am. Phil. Soc.,) it will be found that astronomer makes the following remarks: "In 1836, Olbers, the original proposer of the theory of 1795, being firmly convinced of the correctness of Brandes's estimate of the relative velocity of meteors, renounces his *selenic* theory, and adopts the *cosmical* theory as the only one which is adequate to explain the established facts before the public."

For reasons already stated, it appears wrong to assume the identity of meteorites and shooting stars; so that whatever difficulty the phenomena of the latter may have interposed as to the hypothesis of the origin of meteoric stones, it now no longer exists. Had Olbers viewed the matter in this light, he would doubtless have retained his original convictions, to which no material objection appears to have occurred to him for forty years.

It is not my object to enter upon all the points of plausibility of this assumed origin, or to meet all the objections which have been urged against it. The object now is simply to urge such facts as have been developed in this lecture, and which appear to give strength to the hypothesis. They may be summed up under the following heads:

1. That all meteoric masses have a community of origin.
2. At one period they formed parts of some large body.
3. They have all been subject to a more or less prolonged igneous action corresponding to that of terrestrial volcanoes.
4. That their source must be deficient in oxygen.
5. That their average specific gravity is about that of the moon.

From what has been said under the head of common characters of meteorites, it would appear far more singular that these bodies should have been formed separately, than that they should have at some time constituted parts of the same body; and from the character of their formation, that body should have been of great dimensions. Let us suppose all the known meteorites assembled in one mass, and regarded by the philosopher, mindful of our knowledge of chemical and physical laws. Would it be considered more rational to view them as the great representatives of some one body that had been broken into fragments, or as small specks of some vast body in space that at one period or another has cast them forth? The latter it seems to me is the only opinion that can be entertained in reviewing the facts of the case.

As regards the igneous character of the minerals composing meteorites, nothing remains to be added to what has already been said; in fact no mineralogist can dispute the great resemblance of these minerals to those of terrestrial volcanoes, they having only sufficient difference in association to establish that although igneous, they are extra-terrestrial. The source must also be deficient in oxygen, either in a gaseous condition, or combined, as in water; the reasons for so thinking have been clearly stated as dependent upon the existence of *metallic iron* in meteorites—a metal so oxydizable that in its terrestrial associations it is almost always found combined with oxygen, and never in its metallic state.

What, then, is that body which is to claim common parentage of these celestial messengers? Are we to look at them as fragments of some shattered planet whose great representatives are the thirty-three asteroids between Mars and Jupiter, and that they are "minute outriders of the asteroids," (to use the language of R. P. Greg, jr.,* in a late communication to the British Association,) which have been ultimately drawn from their path by the attraction of the earth? For more reasons than one this view is not tenable. Many of our most distinguished astronomers do not regard the asteroids as fragments of a shattered planet; and it is hard to believe, if they were, and the meteorites the smaller fragments, that these latter should resemble each other so closely in their composition—a circumstance that would not be realized if our earth was shattered into a million of masses, large and small.

If, then, we leave the asteroids and look to the other planets, we find nothing in their constitution, or the circumstances attending them, to lead to any rational supposition as to their being the original habitation of the class of bodies in question. This leaves us, then, but the *moon* to look to as the parent of meteorites; and the more I contemplate that body the stronger does the conviction grow, that to it all these bodies originally belonged.

It cannot be doubted, from what we know of the moon, that it is constituted of such matter as composes meteoric stones; and that its appearances indicate volcanic action, which when compared with similar action on the face of the globe, is like Ætna contrasted with an ordinary forge, so great is the difference. The results of volcanic throws and outbursts of lava are seen, for which we seek in vain anything but a faint picture on the surface of our earth.. Again, in the support of the present view it is clearly established that there is neither atmosphere nor water on the surface of that body, and, consequently, no oxygen in those conditions which would preclude the existence of metallic iron.

Another ground in support of this view is based on the specific gravity of meteorites—a circumstance that has not been insisted on; and although of itself possessing no great value, yet, in conjunction with the other facts it has some weight.

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* See the able paper of R. P. Greg, jr., in the Lond. Phil. Mag.

In viewing the cosmical bodies of our system with relation to their densities, they are divided into two great classes—planetary and cometary bodies, (these last embracing comets proper and shooting stars,) the former being of dense, and the latter of very attenuated matter; and so far as our knowledge extends, there is no reason to believe that the density of any comet approaches that of any of the planets. This fact gives some grounds for connecting meteorites with the planets. Among the planets there is also a difference, and a very marked one, in their respective densities; Saturn having a density of 0.77 to 0.75, water being 1.0; Jupiter 2.00–2.25; Mars 3.5–4.1; Venus 4.8–5.4; Mercury between 7 and 36; Uranus 0.8–2.9; that of the Earth being 5.67.* If, then, from specific gravity we are to connect meteorites to the planets, as their mean density is usually considered about 3.0,† they must come within the planetary range of Mars, Earth, and Venus. In the cases of the first and last we can trace no connexion, from our ignorance of their nature and of the causes that could have detached them.

This reduces us then to our own planet, consisting of two parts—the planet proper with a density of 5.76, and the moon with a density of about 3.62.‡ On viewing this, we are at once struck with the relation that these bear to the density of meteorites, a relation that even the planets do not bear to each other in their densities.

As before remarked, I lay no great weight on this view of the density, but call attention to it as agreeing with conclusions arrived at on other grounds.

The chemical composition is also another strong ground in favor of the lunar origin. This has been so ably insisted on by Berzelius and others, that it would be superfluous to attempt to argue the matter any further here; but I will simply make a comment on the disregard that astronomers usually have for this argument. In the memoir on the periodic meteors by Sears C. Walker, already quoted from, it is stated, "The chemical objection is not very weighty, for we may as well suppose a uniformity of constituents in cosmical as in lunar substances." From this conclusion it is reasonable to dissent, for as yet we are acquainted with the materials of but two bodies, those of the earth and those of meteorites, and their very dissimilarity of constitution is the strongest argument of their belonging to different spheres. In further refutation of this idea it may be asked, is it to be expected that a mass of matter detached from Jupiter, (a planet but little heavier than water,) or from Saturn, (one nearly as light as cork,) or from Encke's comet, (thinner than air,) would at all accord with each other or with those of the earth? It is far more rational to suppose that every cosmical body, without necessarily possessing elements different from each other, yet are so constituted that they may

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* For these estimates of the densities of the planets, the author is indebted to Prof. Peirce.

† Although the average specific gravity of the metallic and stony meteorites is greater, yet the latter exceeding the former in quantity, the number 3.0 is doubtless as nearly correct as can be ascertained.

‡ Although the densities of the earth and moon differ, these two bodies may consist of similar materials, for the numbers given represent the density of bodies as wholes; the solid crust of the earth for a mile in depth cannot average a density of 3.0.

be known by their fragments. With this view of the matter, our specimens of meteorites are but multiplied samples of the same body, and that body, with the light we now have, appears to have been the moon.

This theory is not usually opposed on the ground that the moon is not able to supply such bodies as the meteoric iron and stone; it is more commonly objected to from the difficulty that there appears to be in the way of this body's projecting masses of matter beyond the central point of attraction between the earth and moon. Suffice it to say, that Laplace, with all his mathematical acumen, saw no difficulty in the way of this taking place, although we know that he gave special attention to it at three different times during a period of thirty years, and died without discovering any physical difficulty in the way. Also, for a period of forty years, Olbers was of the same opinion, and changed his views, as already stated, for reasons of a different character. And to these two we add Hutton, Biot, Poisson, and others, whose names have been already mentioned.

Laplace's view of the matter was connected with present volcanic action in the moon, but there is every reason to believe that all such action has long since ceased in the moon. This, however, does not invalidate this theory in the least, for the force of projection and modified attraction to which the detached masses were subjected, only gave them new and independent orbits around the earth, that may endure for a great length of time before coming in contact with the earth.

The various astronomers cited concur in the opinion, that a body projected from the moon with a velocity of about eight thousand feet per second, would go beyond the mutual point of attraction between the earth and moon, and already having an orbital velocity, may become a satellite of the earth with a modified orbit.

The important question, then, for consideration, is the force requisite to produce this velocity. The force exercised in terrestrial volcanoes varies. According to Dr. Peters, who made observations on Ætna, the velocity of some of the stones was 1,250 feet a second, and observations made on the peak of Teneriffe gave 3,000 feet a second. Assuming, however, the former velocity to be the maximum of terrestrial volcanic effects, the velocity with which the bodies started (stones with specific gravity of about 3.00) must have exceeded 2,000 feet a second to permit of an absorbed velocity of 1,250 feet through the denser portions of our atmosphere.

When we regard the enormous craters of elevation on the moon's surface, the great elevation of these above the general surface, and the consequent internal force required to elevate the melted lava that must have at one time poured from their sides, it is not irrational to assume that bodies were projected from lunar volcanoes at a velocity exceeding seven or eight thousand feet per second. I know that Prof. Dana, in a learned paper on the subject of lunar volcanoes, (Am. J. Sci., [2], ii, 375,) argues that the great breadth of the craters is no evidence of great projectile force, the pits being regarded as boiling craters, where force for lofty projection could not accumulate. Although his hypothesis is ingeniously sustained, still, until stronger proof is urged, we are justified, I think, in assuming the contrary to be true, for we must not measure the convulsive throes of nature at all periods by what our limited experience has enabled us to witness.

With the existence of volcanic action in the moon without air or water, I have nothing at present to do, particularly as those who have studied volcanic action concede that neither of these agents is absolutely required to produce it; moreover, the surface of the moon is the strongest evidence we have in favor of its occurring under those circumstances.

The views here advanced do not at all exclude the detachment of these bodies from the moon by any other force than volcanic. It is useless for us to disbelieve the existence of such force merely because we cannot conceive what that force is; suffice it to know that the meteorites are fragments, and if so, must have been detached from the parent mass by some force. A study of the surface of the moon would induce the belief that any disruption caused by heat might have occurred, as that arising from the great tension produced by cooling, as exists on a miniature scale in Prince Rupert's drops, (a suggestion made by Mr. Naysmith at a recent meeting of the British Association.)

Admit the fragmentary character of meteorites, (which I conceive must be done,) the force that detached it from any planet might with equal propriety detach it from the moon; while, from what is known of that body, everything else would tend to strengthen this belief. In the paper already mentioned as written by Mr. R. P. Greg, jr., advocating the probable connexion between meteoric stones and the group of asteroids, the author cannot altogether get over the probable lunar origin of some of these stones, as will be seen from the following quotation:

"The physical constitution and internal appearance of some ærolites, also, as those of Barbotan, Weston, Juvenas, and Bishopville, are entirely opposed to the idea of an atmospheric origin, or of any consolidation of homologous or nebulous particles existing in the interplanetary space. They are evidently *parts*, as Dr. Lawrence Smith likewise justly insists on, of some larger whole, and are not unfrequently true igneous if not volcanic rocks. Physically speaking, there is little choice left us but to consider some of them certainly as having true geological and mineralogical characteristics; either proceeding from volcanoes in the moon, or portions of a broken satellite or planetary body: there may, indeed, be difficulties and objections to either supposition. I have principally endeavored to adduce arguments in favor of the latter idea, stating also some apparently strong objections to the (at least universal) lunar origin of ærolites and meteoric iron masses."

But it may be very reasonably asked, Why consider the moon the source of these fragmentary masses called meteorites? May not smaller bodies, either planets or satellites, as they pass by the earth and through our atmosphere, have portions detached by the mechanical and chemical action to which they are subjected? To this I will assent as soon as the existence of that body or those bodies is proved. Are we to suppose that each meteorite falling to the earth is thrown off from a different sphere which becomes entangled in the atmosphere? If so, how great the wonder that the earth has never intercepted one of those spheres, and that all should have struck the stratum of air surrounding our globe, (some fifty miles in height,) and escaped the body of the globe 8,000 miles in diameter. It is said that the earth has never intercepted one of these spheres; for if we collect together all the known meteorites, in and out of cabinets, they would hardly cover the surface of a good sized room, and no one of them could be looked upon as the maternal mass upon which we might suppose the others to have been grafted; and this would appear equally true, if we consider the known meteorites as representing not more than a hundredth part of those which have fallen.

If it be conceived that the same body has given rise to them, and is still wending its path through space, only seeming by its repeated shocks with our atmosphere to acquire new vigor for a new encounter with that medium, the wonder will be greater, that it has not long since encountered the solid part of the globe; but still more strange, that its velocity has not been long since destroyed by the resistance of the atmosphere, through which it must have made repeated crossings of over 1,000 miles in extent.

But it may be said that facts are stronger than arguments, and that bodies of great dimensions (even over one mile in diameter) have been seen traversing the atmosphere, and have also been seen to project fragments and pass on. Now, of the few instances of the supposed large bodies, I will only analyze the value of the data upon which the Wilton and Weston meteorites were calculated; and they are selected, because the details connected with them are more accessible. The calculations concerning the latter were made by Dr. Bowditch; but his able calculations were based on deceptive data; and this is stated without hesitation, knowing the difficulty admitted by all of making correct observations as to size of luminous bodies passing rapidly through the atmosphere. Experiments, that would be considered superfluous, have been instituted to prove the perfect fallacy of making any but a most erroneous estimate of the size of luminous bodies, by their apparent size, *even when their distance from the observer and the true size of the object are known;* how much more fallacious, then, any estimate of size made, where the observer does not know the true size of the body, and not even his distance very accurately.

In my experiments, three solid bodies in a state of vigorous incandescence were used: 1st, charcoal points transmitting electricity; 2d, lime heated by the oxy-hydrogen blowpipe; 3d, steel in a state of incandescence in a stream of oxygen gas. They were observed on a clear night at different distances, and the body of light (without the bordering rays) compared with the disk of the moon, then nearly full, and 45° above the horizon. Without going into details of the experiment the results will be tabulated.

	Actual diam. as seen at 10 in.	Apparent diam. at 200 yards.	Apparent diam. at ¼ mile.	Apparent diam. at ⅓ mile.
Carbon points.....	.3 of an inch.	⅓ diam. moon's disk.	3 diam. moon's disk.	3¼ diam. moon's disk.
Lime light........	.4 " "	⅙ " "	2 " "	2 " "
Incandescent steel	.2 " "	¼ " "	1 " "	1 " "

If, then, the apparent diameter of a luminous meteor at a given distance is to be accepted as a guide for calculating the real size of these bodies, the

Charcoal points would be 80 feet diam. instead of $\frac{3}{10}$ of an inch.
Lime " " 50 " " $\frac{4}{10}$ "
The steel globule " 25 " " $\frac{2}{10}$ "

It is not in place to enter into any explanation of these deceptive appearances, for they are well-known facts, and were tried in the present form only to give precision to the criticism on the supposed size of these bodies. Comments on them are also unnecessary, as they speak for themselves. But to return to the two meteorites under review.

That of Wilton was estimated by Mr. Edward C. Herrick (American Journal of Science, vol. xxxvii, p. 130) to be about 150 feet in diameter. It appeared to increase gradually in size until *just before the explosion*, when it was at its largest apparent magnitude of one-fourth the moon's disk—exploded 25° to 30° above the horizon with a heavy report, that was heard about thirty seconds after the explosion was seen. One or more of the observers saw luminous fragments descend towards the ground. When it exploded, it was three or four miles above the surface of the earth; immediately after the explosion, it was no longer visible. The large size of the body is made out of the fact of its appearing one-fourth the apparent disk of the moon at about six miles distant. After the experiments just recorded, and easy of repetition, the uncertainty of such a conclusion must be evident; and it is insisted on as a fact easy of demonstration, that a body in a state of incandescence (as the ferruginous portions of a stony meteorite) might exhibit the apparent diameter of the Wilton meteorite at six miles distance, and not be more than a few inches or a foot or two in diameter, according to the intensity of the incandescence.

Besides, if that body was so large, where did it go to after throwing off the supposed small fragments? The fragments were seen to fall; but the great ignited mass suddenly disappeared at 30° above the horizon, four miles from the earth, when it could not have had less than six or seven hundred miles of atmosphere to traverse before it reached the limit of that medium. It had already acquired a state of ignition in its passage through the air prior to the explosion, and should have retained its luminous appearance consequent thereupon, at least while remaining in the atmosphere; but as this was not the case, and a sudden disappearance of the entire body took place in the very lowest portions of the atmosphere, and descending luminous fragments were seen, the natural conclusion appears to be, that the whole meteorite was contained in the fragments that fell.

As to the Weston meteorite, it is stated that its direction was nearly parallel to the surface of the earth, at an elevation of about 18 miles; and was one mile further when it exploded. The length of its path from the time it was seen until it exploded was at least 107 miles; duration of flight estimated at about thirty seconds, and its relative velocity three and a half miles a second. It exploded; three heavy reports were heard; *the meteorite disappeared at the time of the explosion.*

As to the value of the data upon which its size was estimated, the same objection is urged as in the case of the Wilton meteorite; and it is hazarding nothing to state that the apparent size may have been due to an incandescent body a foot or two in diameter. Also, with reference to its disappearance, there is the same inexplicable mystery. It is supposed from its enormous size that but minute fragments of it fell; yet it disappeared at the time that this took place, which it is supposed occurred 19 miles above the earth; (an estimate doubtless too great when we consider the heavy reports.)

Accepting this elevation, what do we have? A body one mile and a half in diameter in a state of incandescence, passing in a curve almost parallel to the earth, and while in the very densest stratum of air that it reaches, with a vigorous reaction between the atmosphere and its surface, and a dense body of air in front of it, is totally eclipsed; while, if it had a direction only tangential to the earth, instead of nearly parallel, it would at the height of 19 miles have had upwards of 500 miles of air of variable density to traverse, which at the relative velocity of 3½ miles a second (that must have been constantly diminishing by the resistance) would have taken about 143 seconds. It seems most probable that if this body was such an enormous one, it should have been seen for more than ten minutes after the explosion, for the reasons above stated. The fact of its disappearance at the time of the explosion, is strong proof that the mass itself was broken to fragments, and that these fragments fell to the earth; assuring us that the meteorite was not the huge body represented, but simply one of those irregular stony fragments which, by explosion from heat and great friction against the atmosphere, become shattered. I say irregular, because we have strong evidence of this irregularity in its motion, which was "scolloping," a motion frequently observed in meteorites, and doubtless due to the resistance of the atmosphere upon the irregular mass, for a spherical body passing through a resisting medium at great velocity would not show this. In fact, if almost any of the specimens of meteorites in our cabinets were discharged from a cannon, even in their limited flight, the scolloping motion would be seen.

This, then, will conclude what I have to say in contradiction to the supposition of large solid cosmical bodies passing through the atmosphere, and dropping small portions of their mass. The contradiction is seen to be based, first, upon the fact that no meteorite is known of any very great size, none larger than the granite balls to be found at the Dardanelles alongside of the pieces of ordnance from which they are discharged; secondly, on the fallacy of estimating the actual size of these bodies from their apparent size; and lastly, from its being opposed to all the laws of chance that these bodies should have been passing through an atmosphere for ages, and none have yet encountered the body of the earth.

To sum up the theory of the lunar origin of meteorites, it may be stated—*That the moon is the only large body in space of which we have any knowledge, possessing the requisite conditions demanded by the physical and chemical properties of meteorites; and that they have been thrown off from that body by volcanic action, (doubtless long since extinct,) or some other disruptive force, and, encountering no gaseous medium of resistance, reached such a distance as that the moon exercised no longer a preponderating attraction—the detached fragment possessing an orbital motion and an orbital velocity, which it had in common with all parts of the moon, but now more or less modified by the projectile force and new condition of attraction in which it was placed with reference to the earth, acquired an independent orbit more or less elliptical. This orbit, necessarily subject to great disturbing influences, may sooner or later cross our atmosphere and be intercepted by the body of the globe.*

LECTURE.

ON PLANETARY DISTURBANCES.

BY PROF. E. S. SNELL,
OF AMHERST COLLEGE, MASSACHUSETTS.

The laws of force and motion are everywhere the same. Whether a pebble be thrown by the hand of a child, or a world be launched into space by the will of the Creator, the same laws will forever govern the movements of the two bodies, and the same principles will be employed to calculate their paths. If no second force operates to disturb them, they will pursue a straight course, and at a uniform rate for endless ages. But should a *second* impulse be applied to the moving body, and in some other direction, it will follow neither its original track nor that of the *new* force, but will describe a line between the two, which can be precisely determined, both in direction and velocity, from the magnitude and direction of the two forces. And this intermediate line will be as exactly straight, and described with a velocity as perfectly uniform, as though but one force had originated the motion. This is denominated compound motion; but it is the *force* which is compound, not the *motion.*

If the body, which has commenced its rectilinear path, should be subject to an *attractive* force urging it towards some centre, and increasing as the square of the distance diminishes, and *vice versa*, then it will move in an orbit about that centre; and this orbit will inevitably be one of the figures called the conic sections, in the focus of which the attracting body resides. The stone thrown by the hand, and describing a path bent towards the earth, has in fact begun to move in such an orbit; and if the earth could attract it by the usual law of gravity, and at the same time present no obstruction to its course, the stone would descend with increasing velocity, pass around the centre within the distance of a few feet, and with a speed of many thousands of miles per second, then ascend more and more slowly to its place of departure, and thus, after the lapse of a few minutes from the time it was thrown, be ready to begin the same journey anew; and this elliptical circulation would be continued forever, if no new force should come in to prevent. The path of a projectile near the earth is usually called a parabola; and for all the purposes of calculation it is sufficiently near the truth; for the extremity of so eccentric an ellipse is infinitely near to a parabola, and this curve is much more simple than the ellipse. So the upright corners of a building are considered parallel lines, though in fact they converge towards the earth's centre.

The same principles which determine for us the resultant movement under the action of *two* forces will also enable us to find it, when *three,* *four*, or *any number* of impulses are applied. And the thought I wish particularly to present is, that these results of calculation are just the same in all the movements of common life, in the operations of every machine, and in the revolutions of the moons, planets, comets, and suns of the universe. There is not one system of mechanics for rolling marbles, playing ball, and pitching quoits; another for guiding ships and railroad cars, and driving machinery; and a third for maintaining the revolutions of days and seasons on the planets, and working out the grand harmonies of creation. Here, as in every department of God's works, we see infinite variety comprehended in a simple unity.

This identity in the laws of terrestrial mechanics and of "mechanics celestial" affords the highest satisfaction to the student of astronomy. He feels that he is treading on safe ground; he sees it to be as preposterous to suppose the foundations of the present system of astronomy subverted, and Newton's Principia and La Place's Méchanique Celeste giving way to some new method of explaining the movements of worlds, as to imagine that philosophers should abandon the principles of projectiles, the laws which fix the relations of wheels, levers, and screws in a machine, or the methods of calculating and applying the forces used in locomotion, and should substitute in their place some new system of principles and laws.

Perhaps I ought to state the exact meaning of two words which I shall occasionally use—*inertia* and *gravitation*. *Gravitation* is the tendency of all masses of matter in the universe towards each other, which tendency varies directly as the quantity, and inversely as the square of the distance. *Inertia* is a negative term, implying that matter is unable to change its condition as to motion and rest. If a body is at rest, it will never move, unless a force acts upon it; if it is in motion, it will forever move in the same straight line, and at the same rate, if no external force causes a change. A mass of matter can no more stop, or go faster or slower, or change its line of motion, than it can begin to move from a state of rest.

These two properties of matter explain not only the ordinary facts of terrestrial mechanics, and those phenomena of astronomy which were known in the days of Sir Isaac Newton, but a vast number of other planetary movements and disturbances, some of them most delicate and intricate, which have since been detected. Not a new fact as yet has come to light which conflicts with these simple first principles. No system but the true one could bear a test like this.

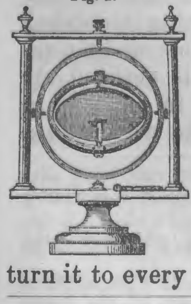
In attempting to give experimental illustrations of astronomical movements, we meet with difficulties which cannot be entirely removed. The earth attracts; the air obstructs: a revolving body must be supported by pivots; these retard by friction. The best contrived experiments, therefore, are only approximations to the phenomena which they are intended to illustrate.

A fundamental fact in rotation, whether on an axis or in an orbit, and one, too, which is a direct consequence of inertia, is this: a revolving body tends to keep its plane of rotation always parallel to itself. This fact is apparent in all the bodies of the solar system. For example, the earth, though it travels over a journey of six hundred millions of miles every year, maintains its equator parallel to itself, its north pole all the time pointing nearly in the direction of the so-called north star. Were it not so, our seasons would not be preserved. Let this horizontal wooden ring represent the plane of the ecliptic, the lamp in the centre the sun, and the six-inch globe revolving on the axis which I hold, the earth. As I carry the globe around the ring, with the equator oblique to it, and keep the axis directed to the same point in the sky, you perceive that the upper pole is now in the light of the lamp; now, after a quarter revolution, the light just reaches to both poles; and now, when carried half round, the upper pole is turned away from the light, and the lower one towards it; and, once more, after three-quarters of a revolution, both poles are again in the edge of the enlightened hemisphere. The axis being held parallel to itself, and the globe all the time spinning upon it, you perceive that the upper hemisphere in the first position has the long days and short nights of summer; in the second, the equal days and nights of autumn; in the third, the short days and long nights of winter; and in the last, the equal days and nights of spring. In the lower hemisphere, all these facts are reversed. So, also, the *moon's* axis is not exactly perpendicular to the plane of its orbit; and, as its equator continues parallel to itself, we alternately see the north and south poles of the moon presented to us—a phenomenon called the moon's libration in latitude. In the foregoing illustration, we have only to suppose the wooden ring to be the moon's orbit, and the small globe the moon, while the lamp in the centre occupies the place of the earth.

In like manner, the orbits and equators of all the planets and satellites in the system show plainly a tendency to maintain a parallelism at all times. That these planes are not really and precisely parallel, is the result of disturbing influences, to be noticed presently.

In order to show this tendency experimentally, it is necessary that the revolving body should be free to place its axis in all directions. This is done by swinging it in gimbals, somewhat like the mariner's compass. The instrument before you was called by the inventor, the late Professor Walter R. Johnson, the Rotascope.* It very much resembles Bohnenberger's apparatus for illustrating the precession of the equinoxes, but is many times larger, and has several appendages for various experiments on rotatory motion. The outer brass ring is free to revolve on a vertical axis in the wooden frame; the inner ring can revolve freely on a horizontal axis in the outer one; and the spheroid in the inner ring has its axis perpendicular to that of the ring itself. (Fig. 1.) Thus, you perceive, the spheroid, by means of the rectangular axis, is free to revolve in any plane whatever. I now set it spinning, (by looping a cord upon the small pin in the axis, winding it up, and then drawing the ends apart till it is unwound and detached,) and elevate somewhat that end of the axis which is nearest to you, that you may see its position better. I now take up the frame in my hands, and carry it about the platform, and turn it to every point of the compass, and tip it over to any angle, even

Fig. 1.



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* See Professor W. R. Johnson's "Description of the Rotascope," in the American Journal of Science and Arts, for January, 1832, p. 265, *et seq.* The instrument used in

bottom up, and yet the axis of the spheroid remains parallel to itself, with the elevated end directed towards you.

Fig. 2.

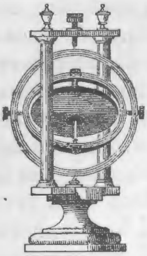


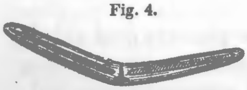
Fig. 3.

Friction on the pivots, and resistance of the air, will cause small changes of direction, especially if I move the frame violently.*

If a body, therefore, were made to revolve on an axis, it might be carried or driven anywhere into space, without ever changing the position of its plane of rotation, unless the forces applied should act unequally on the parts of the body.

We find an elegant illustration of this tendency to parallelism of axis in the boomereng, a curious missile used by the natives of New South Wales, an account of which is given by Captain Wilkes in his "Exploring Expedition."† It is made of wood, about three feet long, two inches wide, and three-fourths of an inch thick, bent in the middle at an obtuse angle, somewhat resembling a rude sword. (Fig. 4.) The article which I hold in my hand is an actual boomereng, brought by the explorers, and belonging to the collections of the Smithsonian Institution. Three or four others may be seen in the National Gallery, in the building of the Patent Office. It is thrown with a rapidly revolving motion, and is said to be very effective both in war and hunting. Those who are skilled in its use can throw it obliquely upward so that it will come back to them, or even pass over their heads, and hit any desired object behind them. It would be hardly safe for me to try the experiment here, lest (lacking the skill of the savage) I should hurt either you or myself. I can with less hazard, project these models, made of stiff card, and only three or four inches long. Holding one of these with the obtuse angle between my thumb and finger, I snap the end forcibly, so as to send it off obliquely upward, with a swift rotation in its own plane, and you perceive that instead of describing the usual path of a projectile, after completing its ascent, it returns in the same plane, and falls near me. If several be thus snapped off in different directions, occasionally one will perform an awkward somerset, but most of them will come back to me. It is that tendency (already spoken of) in a rotating body, to preserve its

Fig. 4.



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this lecture is of more simple construction, the orbit-rod and the third ring being dispensed with, as they are wholly unnecessary for the illustration of composition of rotary motions.

* In figures 1, 2, 3, the spheroid is seen maintaining the same position, while the frame is placed in various positions.

† For a description of the boomereng, and its uses, see Captain Wilkes's "Narrative of the United States Exploring Expedition," vol. II, pp. 191, 192.

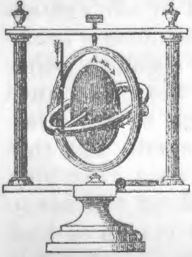
axis parallel to itself, which explains this apparently singular phenomenon. Observe that as the boomereng ascends, it is whirling on an axis perpendicular to the plane of ascent. Should it go onward in its descent, and cut the air edgewise, it must necessarily change its plane of rotation ; it will not, therefore, do this. If it goes on, keeping its axis parallel to itself, it must strike broadside through the air, and the resistance is too great to allow of this. The only way in which it can maintain a parallelism of rotation, and yet cut the air edgewise, and also descend with the largest angle of inclination, is to come back to its place of projection, as you have seen it do. It does, in fact, as the foregoing explanation requires, ascend and descend on an *inclined plane,* instead of pursuing the *parabolic* or *atmospheric* curve at all.

But I have already intimated that, in the solar system, this parallelism is rarely, if ever, perfectly maintained. The earth's equator deviates at a very slow rate, (about fifty seconds in a year,) so that for many years it was not perceived by the rude means of measurement which ancient astronomers possessed. But its deviation has been going steadily on in the same direction, until the signs of the zodiac and the signs of the ecliptic are now separated by the extent of an entire sign, or thirty degrees. The plane of the moon's orbit deviates from parallelism much faster, so that in about eighteen years it inclines in every direction at its given angle with the orbit, and comes round again into its former position. Going back to our first illustration, in which the small globe represents the earth, and the wooden ring the ecliptic, I carry the globe round the ring, from the west side, through the south, to the east, and onward, at the same time inclining the north pole towards me, so that the planes of the equator and the ecliptic intersect in an east and west line. But, after I have carried it round a number of times, please to observe that I shift the position of the axis, by which I hold the globe, in such a manner that the line of intersection lies a little to the south of east and north of west. The ends of that line, representing the equinoxes, have moved a little from the east (through the south) to the west ; that is, in a direction contrary to that in which the earth revolves. At length, as the revolutions proceed, the line of equinoxes is found lying north and south ; and thus it perpetually retrogrades. This is called the "Precession of the equinoxes." It is so exceedingly slow, that in order to describe ninety degrees, as just represented, it will require between 6,000 and 7,000 years, and, therefore, about 26,000 years to complete the circuit of the heavens. Again, if I carry this two-inch brass ball round from west to east, but oblique to the wooden ring, passing above it through the southern half, and below it through the northern, we shall have a representation of the moon's path around the earth, oblique to the ecliptic. The intersecting points, called the nodes, now lie in an east and west line ; but as I carry it round repeatedly, I make the ball descend below the ecliptic, at a point a little further to the west, every time, and thus cause the line of nodes to move *backward,* while the moon itself goes *forward.* This is called the "Retrogradation of the moon's nodes." It is vastly more rapid than the precession just described, since the line of the nodes passes quite round the sky in eighteen or nineteen years.

Now, these nodal motions in the solar system, of which I have named the two most familiar examples, are the effects of some disturbing force; for we have seen that, without disturbance, the plane of rotation would be forever parallel to itself, and would therefore cut a fixed plane always in the same points. I have already alluded to the law of composition in *rectilinear* motions; namely, that the resultant motion lies between the directions of the two component forces, dividing the angle into two parts, which have a very simple relation to the magnitude of the forces, the body moving most nearly in the direction of the greater force. The law of composition of *rotary* motions is quite analogous to it, and directly deducible from it. It is this: If a body is revolving on an axis, and a force is applied tending to revolve it on some other axis, it will not revolve on either, but on a third one, between the two, and dividing the angle as before.*

To show you the truth of this law, I whirl the spheroid of the rotascope, so that, while the south end of the axis points from me, the particles pass over from my left to my right. Now, with this smooth rod, I press down the north side of the inner ring, thus tending to give the spheroid a similar right-hand rotation on an axis pointing westward. The effect is, you perceive, that the ring slips round under the rod, so as to bring the south end of the axis into the southwest quarter—that is, *between* the two axes of separate rotation. If I continue the pressure, the axis passes round still farther west, endeavoring each moment to place itself between its present position and one at right angles to itself.† If there were no friction under the rod and on the pivots, this horizontal rotation would continue so long as the pressure is applied, and more rapidly as the pressure is greater. But, as there *is* friction, the south end of the axis slowly rises from a horizontal plane. I now direct the axis again towards the south, and press the north side of the ring *upward*—that is, I endeavor to produce a right-handed rotation on an axis pointing *eastward;* and you see the south pole immediately pass round towards the *east*, between the two axes.

Fig. 5.



As all the cases of compound rotation are more easily described by

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* I did not think it best, in a popular lecture, to give a full and technical statement of the laws of composition, in either rectilinear or rotary motions. They are subjoined here for the use of any who may wish to recur to them:

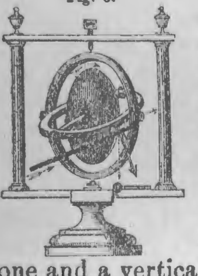
"If a particle receives two motions, which are separately represented by the adjacent sides of a parallelogram, the resultant motion is represented by the diagonal of the same; and therefore, in *direction*, it divides the angle of the components, so that the sines of the two parts are inversely as the components; and in *quantity*, it has to *either* component the same ratio as the sine of the whole angle has to the sine of the part between itself and the *other* component."

The law of compound *revolutions* is this: "If a body receives two impulses, one of which would cause it to revolve on *one* axis, and the other on a *second*, it will revolve on a *third* axis, situated between the two, and dividing their angle, so that the sines of the parts are inversely as the two impulses. And the velocity of rotation is to the velocity due to *either* impulse, as the sine of the angle between the two original axes is to the sine of the partial angle between the third axis and that on which the *other* impulse would have revolved the body."

† In figure 5, the particles at A, moving in the direction of the arrow by the revolution of the spheroid, and also urged towards the rod, by which the ring is pressed down, move *between* these two directions; this is effected by the sliding of the ring towards the left, under the rod, as shown by the *double-shaft* arrow.

directing attention to the revolving particles themselves, rather than to the axes of motion, and as this mode renders more obvious the resemblance between compound *rotary* and compound *rectilinear* motions, I will adopt that method of explanation in the remaining experiments. The spheroid having lost considerable velocity, I renew it, and once more direct the axis southward, observing that the particles on the west side are moving *downward*. I now press the west side of the outer ring towards the *south*, and you see that the only effect is to make the south pole *rise up;* if I push the same side *north*, the south pole is *depressed*. Now observe the reason. The particles on the west side, moving *down* by one motion, and *south* by the other, take an intermediate direction, which necessarily elevates the south pole. The particles on the east side conspire in this effect; for, by the first rotation they move *upward;* by the pressure which I communicate they are urged *northward;* and, taking a direction between these two, they also throw the south pole *up*. Thus every particle, on the east half and on the west, has a compound motion, which tends to *raise* the south pole of the spheroid; that is, to give the spheroid a revolution on an axis between the two original ones, one of which was directed horizontally southward, the other vertically upward.* If the pressure is continued gently for a few moments, the axis continues to rise, always seeking a new position, between its present one and a vertical one, until, at length, it becomes vertical itself; then the two revolutions coincide, and the ring for the first time yields to the pressure, and goes round in the same direction as the spheroid. I now give a new form to the experiment, by pressing the *east* side southward for several seconds; you perceive the *north* pole of the spheroid elevating itself, till it finally points to the zenith, when the two revolutions agree in a direction, the reverse of the former.

Fig. 6.



Another mode of exhibiting these last experiments is quite calculated to deceive the student and lead him to suppose that the diurnal and annual revolutions of a planet or satellite, are performed in the same general direction from some mechanical necessity. I whirl the spheroid on a vertical axis, from west (through south) to east; next I confine the outer ring, by turning up the fork attached to the bottom of the frame, so as to embrace the edge of the ring; and then, taking the frame by its two pillars, I commence carrying it round myself, from west to east. The spheroid, in the mean time, spins quietly on its axis. But the moment I stop and begin to carry the frame round from east to west, the spheroid suddenly throws itself over, and revolves on a vertical axis still, but with its poles reversed. By this inversion of axis, the spheroid revolves also from east to west, the same direction in which I am carrying the frame. Once more I reverse the orbit motion, and instantly you see the spheroid turn over, seeming determined (if I may borrow some convenient terms from astronomy) to revolve *diurnally* in the same direction in which I carry

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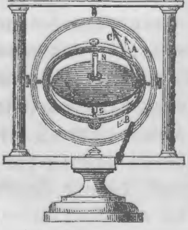
* Fig. 6. The particles at A, moving by the revolution of the spheroid, and the pressure of the rod, respectively in the directions of the *broken-shaft* arrows, take the intermediate direction indicated by the *double-shaft* arrow; which can be done only by the rising of the remote end of the axis.

it *annually*. And so it will do, as often as I change the order of the circular motion. If I press very gently, to produce the orbit motion, without actually *moving*, the spheroid reverses its axis *slowly;* but if I begin to move rapidly, it throws itself over with such energy that it nearly jerks the frame out of my hands.

Now we cannot infer from this experiment, that the axial and orbital revolutions of a planet are so connected, that one must be in the same direction as the other. If the earth were to be stopped in its orbit, and sent backward through the signs of the ecliptic, that would be no reason for its throwing itself over with its north pole to the south, and its south pole to the north. The diurnal rotation would go on undisturbed; for we have already seen that the earth or any revolving body might be projected in any way whatever through space, without causing the least displacement of its axis. This experiment is exactly in point for illustrating the composition of two revolutions, which is the topic now in hand. I make the spheroid to rotate from west to east; I then begin to carry it round me from east to west. This is in fact nothing else than turning it *on its own axis* from east to west; for, when I commence, the side of the frame nearest to me (and of the ring, confined to the frame) faces *north;* after a quarter revolution, the same side faces *east*; after a half revolution, *west;* and so through all points of the compass. So far as the spheroid is concerned, it is the same as though I take hold of the frame, and turn it round in its place on the table. I repeat the experiment in that manner; and you perceive that the instant I turn the frame and confined ring from east to west, the spheroid reverses its poles; and on my turning it back, from west to east, it reverses again, thus resuming its original position. Now here is no orbit-motion; the body stays in its place, and exhibits the resultant effect of two rotations. Let us examine this case of composition. Please to notice that the axis is not *free* to place itself in any position when I move the frame; the spheroid cannot, therefore, maintain a parallel position; but is, on the contrary, constrained to receive a second revolution, which I impress upon it. This second revolution is round a vertical axis, whether I carry the frame about me, or turn it on the table. So long as the spheroid keeps its own axis precisely vertical, although revolving in the opposite direction, it does not tend to turn over, but revolves with the difference of the two motions, which are in the same plane. But the axis of the spheroid will inevitably be jarred slightly from its vertical position; and if so, it cannot recover it. If, for example, the upper pole is jarred towards me, each particle on the right hand will, by the first rotation, be moving from me in a line slightly ascending; and, by the second, horizontally towards me; thus the two forces will act at a large obtuse angle, within which the particle will direct itself, throwing the upper pole farther towards me.* The angle of the forces is thus diminished a

Fig. 7.



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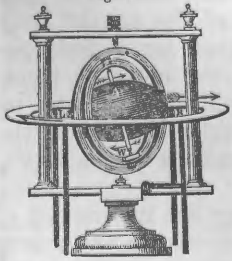
* In figure 7, the particles at R *ascend from* the observer in the line of the arrow A, by the revolution of the spheroid; and move *horizontally towards* him in the line of the arrow B, by pressure on the frame; they, therefore, move *between*, as shown by the arrow C; that is, the upper end of the axis N moves *towards* him.

little, and the next resultant lies within this diminished angle; and so, by the continued pressure on the frame, the angle is reduced to nothing, by the complete reversal of the poles. At that moment, the two forces coincide in direction; and *now*, if the axis is jarred a little, the angle is acute, the resultant lies within it, and tends to bring them to immediate coincidence without upsetting the spheroid. We see, therefore, that there is a condition of *equilibrium*, whichever way the frame is turned on a vertical axis, provided the spheroid revolves also on a vertical axis; but if the revolutions are in the same direction, the equilibrium is stable; if in opposite directions, it is unstable.

We are now prepared to attend to the explanation and illustration of the "Precession of the equinoxes." The earth is not an exact sphere. If it was a sphere, and of uniform density, there would be no such phenomenon as precession. The equator of the earth, as is true also of the other planets, is a little bilged beyond the spherical form, in consequence of its rotation. We conceive of the earth, therefore, as consisting of a sphere with a thin ring attached to its equator. This equatorial ring is inclined about twenty-three and a half degrees to the plane of the ecliptic. The sun is always *in* the ecliptic, and the moon is always very nearly in it. By the attraction of these bodies the equatorial ring is slightly pressed towards the ecliptic, and the whole mass of the earth, being united to the ring, is thus urged to turn into the plane of the ecliptic, on an axis passing through the intersection of the two planes. But in the mean time the earth is also turning on the axis which passes through its poles. By the composition of these two revolutions it begins to turn on a new axis very near the original one, and between it and the line of equinoxes. But the depressing force continues, tending to tip the equator towards the ecliptic on a line still at right angles to the diurnal axis, and therefore shifts that axis again; and thus the cause, and its consequent effect, are repeated from moment to moment for ages. The earth's axis is ever seeking a *new* position between its *present* one and another at *right angles to the present* one.

The rotascope illustrates this perfectly. I first set the horizontal ring around the frame, to represent the ecliptic. The spheroid of the rotascope represents the earth; though, for convenience, it has an excessive oblateness, the equatorial ring being even larger than the enclosed sphere. The earth I set in rotation on its axis from west to east, and incline the equator to the ecliptic; and now I attach this brass weight to the lower edge of the inner ring; the weight, by urging the *ring* into a vertical position, of course presses the *equator* of the spheroid into a horizontal plane—that is, the plane of the ecliptic. The line of equinoxes, you perceive, now lies east and west; but if I leave the apparatus thus adjusted to itself, this line commences a slow revolution from east to west. This is the "Precession of equinoxes."*

Fig. 8.



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* In figure 8, the particles at A, revolving *to the right* with the spheroid, and urged *towards* the observer by the weight W, take an *intermediate* direction; that is, the equinoctial points,

If the attraction of the sun and moon was greater than it is, we reason that the precession would be more rapid; and if less, it would be slower. The experiment is easily modified, to show the correctness of these conclusions. I take off the weight, and put on a heavier, and the horizontal movement is hastened; if I put on a smaller weight you see it slackened; and finally, if I remove the weights altogether, the phenomenon ceases, as it should do.

Once more, we know that if the earth were to revolve more rapidly on its axis than it now does, the present attraction of the sun and moon would produce less effect to change the axis; in other words, the precession would be slower, and *vice versa.* In illustration of this, observe that, as the spheroid loses some of its velocity, (with a given weight on the ring,) the horizontal circulation is gradually gaining speed; and so it will continue to do as long as I let the experiment continue.

We may here notice why the precession is so excessively slow:

1st. The ring of matter on which the sun and moon act is an exceedingly small fraction of the whole earth.

2d. It is not the *whole* attraction of those bodies upon the ring which causes this disturbance, but only that part by which it exceeds or falls short of the attraction on the internal portions.

3d. It is not even the *whole* of this *difference*, but only that component which is perpendicular to the plane of the ecliptic.

4th. The ring cannot move *alone*, in obedience to this influence, but must carry the entire earth with it.

No wonder, then, that the effect is almost too small to be observed. We may well say, when explaining the seasons, that the earth's axis is, in every part of its orbit, parallel to itself.

It is interesting to see so delicate a phenomenon as the precession of the equinoxes completely accounted for. A cause is found, which is not only right in the *direction* of its action, but exactly right, too, in *quantity*, to cause this almost insensible disturbance. It is just as small as it *should* be, considering that the *earth* is as *large* as it is, and as *heavy* as it is, and revolves as *often* as it does; that the *ring* is as *small* as it is, *inclined* as it is to the ecliptic, and *confined* as it is to the earth; that the *sun* and *moon* are just as *massive* and as *distant* as they are, and *varying* as they do their relations to the line of the equinoxes. All these, and still other conditions, being *just as they are*, if the precession was any faster or any slower than about *fifty seconds* in the year—that is, about the width of the sun in forty years—then this motion would not be accounted for. But, besides the agreement of calculated results with the observed facts, which so few are able to appreciate, the same phenomenon can be shown by experiments; a body being made to revolve like the earth, and a force being brought to act on it as the sun does on the earth, the phenomenon is artificially produced before our eyes.

It is to be observed that if the equator, having an inclination of 23½° to the ecliptic, directs that inclination every way in the course

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at the screws L and R, revolve horizontally in the direction of the double-shaft arrow. As the component forces are always at right angles with each other, their resultant is perpetually reproduced.

of ages, the poles of the equator must likewise perform a revolution around the poles of the ecliptic at the same slow rate.

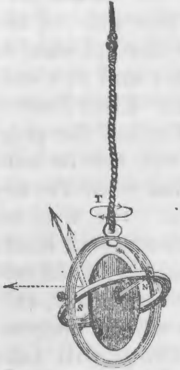
While the rotascope exhibits the precession as in the last experiment, you will perceive, if your attention is given to the *pole* of the spheroid, that it describes a circle around the pole of the ecliptic, or the pivot at the top of the frame. For many years past and to come, the conspicuous star in the extremity of the tail of the Litle Bear is nearly enough in the direction of the earth's axis to be called the pole-star. But the time will come when the little fellow will not be held so unceremoniously by the end of his tail, and whirled round every day without touching feet to the ground, as he now is. He will retire from his dizzy position in the north, and every twenty-four hours will go to rest and rise again, like most other animals. In 13,000 years from this time, the Little Bear will rise in the northeast, culminate over our heads—I should say over the heads of our successors—and set in the northwest; while the beautiful *Harp* will take its station in the northern watch-tower, furnishing a far more brilliant pole-star (Alpha Lyræ) than the one which *we* enjoy.

The retrograde motion of the moon's nodes is explained in the same manner as the precession. The sun is the disturbing body, always in the plane of the ecliptic, while the moon's path about the earth is inclined to the ecliptic about five degrees. A small component of the difference of the sun's action on the earth and moon is employed to press the moon towards the plane of the ecliptic. The two revolutions thus impressed on the moon cause it to revolve in an intermediate direction. Recurring to the experiment by which I illustrated the *fact* of this retrograde motion, a moment's attention, in view of what has been presented on compound rotations, will suffice for understanding the *reason* of it. The wooden ring representing the ecliptic as heretofore, the lamp in its centre the earth, and the brass ball the moon, we must imagine the sun at the distance of some five hundred feet in the extension of the wooden ring. Now, as I carry the ball around the ring obliquely while it is above, and tending, by its inertia and gravity of the earth, to go forward in its orbit, the distant sun exerts a small force to depress it into the plane of the ring, and it therefore goes *between,* and passes the plane at an *earlier* point than if the sun had not acted; that is, the node has moved backward. At every semi-revolution the same cause is in operation, and the effect is, therefore, perpetually produced on each node. But this retrogradation is far more rapid than the precession, principally because the moon is not attached (as the equatorial ring of the earth is) to a mass vastly larger than itself, to which the motion must be communicated.

Before leaving the subject, I will use the rotascope to perform two experiments which strikingly illustrate the general law of compound rotations.

From the ceiling there is suspended a strong wire, on the lower end of which is a cord, or rather a bundle of cords, about two feet long, terminating in a hook. I take the spheroid and rings from the frame, by raising the pivot-screw at the top, and hang the outer ring on the hook, taking care to keep the axis of the inner ring horizontal. I now spin the spheroid as rapidly as possible, and then whirl the outer ring the same way till the cords are twisted so far as to tend strongly to untwist. Letting go the ring, it commences whirling by the force of torsion; but suddenly the axis of the spheroid throws itself into an oblique position, and instantly arrests the motion of the ring, while the spheroid, with the inner ring, slowly turns itself over.* As soon as it *is inverted, the cords untwist, and twist up in the opposite direction*, the spheroid all the while maintaining its own rotation the same way. When they begin the second time to untwist, the spheroid authoratatively interposes, and takes time to turn over quite leisurely, and get itself ready to whirl in the same direction also. And thus will it operate a number of times before running down.

Fig. 9.



This experiment does not need a separate explanation; it is, in fact, a repetition of the one in which I carried the frame round its vertical axis. But it becomes more striking, for the reasons that the force is more secretly applied by the cord than by the hands; that it is applied uniformly as well as gently; and that it is repeated as often as the cord is twisted up. A short and thick rope of parallel cords is purposely used, that the inversion may be repeated several times before the spheroid loses its velocity. You will observe, that the outer ring does not move at all by the torsion of the cord, while the axis is reversing itself; that force is wholly expended on the spheroid, combining with its own rotation, to produce the inversion of its axis.

To prepare the instrument for the second experiment, I replace it in the frame, take the inner ring with the spheroid from the outer ring, and attach to it, at one end of the spheroid's axis, this stiff rod of brass, about six inches long. One end of the rod terminates in a strong fork, which is slipped tightly upon the ring, and confined by pins. The other end is connected by a hook and swivel, with a wire two feet long. I next remove the cord used in the preceding experiment, and hang up, in its place, the wire with the spheroid attached in the manner just described. Having put the spheroid into swift revolution, I lift it up on one side by the ring, till the rod and axis make a right-angle with the wire. Dropping it now from this position, it does not fall, as one would expect, and hang beneath the wire, nor does it even descend in the least, but commences a *horizontal revolution* about the wire. The spheroid itself revolves *vertically*, but the system *horizontally*. And the whole, weighing fifteen pounds, and having its centre of gravity more than a foot from the support, presents the magical appearance of being held up without force. If I elevate it higher, at an acute angle with the wire, it will sustain

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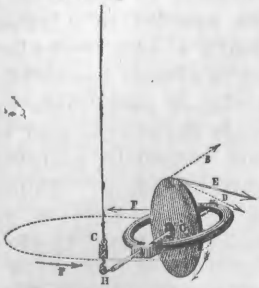
*Figure 9. The arrows T show the direction of torsion. The particles A are moved *upward* by the rotation of the spheroid, and *horizontally to the left* by torsion—these forces being indicated by the *broken-shaft* arrows. The *double-shaft* arrow shows the direction of the resultant, which corresponds to an elevation of the pole N, and a depression of S.

Fig. 10.



itself at that angle, and revolve as before. The direction of the horizontal revolution is the reverse of that which the spheroid has when brought down to hang beneath the wire. For example, in the present experiment, I made the spheroid rotate from W. to E.; and you see the system going from E. to W. I will now revolve the spheroid from E. to W.; and having dropped it again, you observe the revolution to be reversed; the system revolves from W. to E.*

Unaccountable as these phenomena appear at first, they are found to be very obvious cases of compound rotations. Gravity, at first sight, appears to have no effect on the weight, since it is not at all depressed. But it is, in truth, exerting its full energy upon it every moment, producing, in conjunction with the rotation of the spheroid, the horizontal revolution. Let me stop the latter motion for a few moments, that we may examine the manner in which the two forces are compounded. As I hold the spheroid up on the right of the wire, the particles on the top are coming *towards* me; if I should abandon it to the action of gravity, *that* force would urge the same particles to the *right*, in the arc of a vertical circle, described about the hook as a centre; consequently they assume a direction *between* these two directions, which can be done only by the system moving, not downward, but *horizontally from* me. This composition of forces is momentarily repeated, in exactly the same circumstances, and hence the rotation is continued uniformly so long as the spheroid maintains its speed.

There is another species of disturbance in the planetary motions, easily illustrated by experiments, and which will demand but a few moments' attention. The orbits of the planets and satellites, though nearly circular, are really ellipses; and, if no attraction operated on a given revolving body except that of the central body, the ellipse would always present its longest axis in the same direction. But this is not true in fact. The remote end of the longest diameter of the earth's orbit, called its aphelion, which now points to the constellation Gemini, ten thousand years ago was directed to Taurus, and ten thousand years hence will be advanced in the order of the signs to Cancer. This motion is so exceedingly slow that sixty thousand years will be required for the aphelion and perihelion to change places, and one hundred and twenty thousand years to make a full revolution. The extremities of the *moon's* orbit, in like manner, are advancing; but the disturbance in this case is rapid, since they pass entirely round the heavens in about nine years.

You will observe that this line (called the line of the apsides) travels in the same direction as the revolving body, while the line of the nodes moves, as we have seen, the opposite way.

This effect is produced by the action of a body, or of bodies, lying

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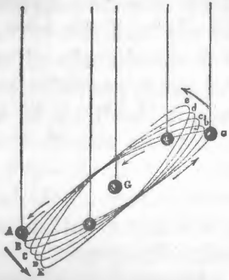
* Fig. 10. The particles at A are moving in the line D, by the rotation of the spheroid, and are urged by gravity towards B, in the plane of a vertical circle around the centre, H. The resultant is towards E, which direction can be attained only by the rotation of the centre of gravity G, in the order of the arrows F, horizontally around the centre C.

outside of the orbit. The sun, for example, outside of the moon's orbit, operates powerfully on it, and causes its apsides to advance rapidly. The superior planets, outside of the earth's orbit, exert but a feeble influence, and the motion of its aphelion is almost insensible.

An exterior body always operates to draw a planet away from its centre; that is, it diminishes its attraction towards the centre, and, of course, it does this most efficiently when the planet is farthest removed from the central body; in other words, when at its aphelion. Hence it advances a little beyond its former aphelion before it turns to go back to the perihelion. Thus each aphelion point is a little further onward than the preceding.

This may be illustrated by a long pendulum. I suspend the small globe by a cord six or eight feet in length. Instead of swinging it back and forth, however, like a pendulum, I throw it round, so as to describe an elliptical orbit. Now, in order to describe this orbit, there must be a *central* force. That force is the component part of gravity, which would, if I should stop the ball, cause it to fall towards the centre, and which would hold it there, and only there, when at rest. I now swing the globe in such a manner, that it will describe from west to east a long narrow orbit, whose longest axis lies north and south. After a few revolutions, the axis is seen shifting a little to the southeast and northwest; and in a few minutes the south has become east, and the north has become west, the apsides having advanced ninety degrees. To show that the two revolutions are necessarily in the same direction, I stop the globe, and revolve it from east to west. You presently notice the axis of the orbit making progress from east to west also.*

Fig. 11.



To explain this change in the pendulum's orbit, I must state a law demonstrated in Newton's Principia; that, when a body revolves in an ellipse about the *centre*, instead of the *focus*, *the attraction to the centre varies as the distance*. When a *long* pendulum is swung in a *small* orbit, this law is proved to obtain almost exactly; and experiment corroborates it. But if the cord is shortened, or the orbit enlarged, the deviation increases, and always in this way—that the central force is not great enough at the extremities of the long axis. Hence, as the body is passing one of these points, the central force being too feeble to bring it back in the former path, it shoots forward a little before turning to come back; that is, the apsis is advanced slightly. This occurs at every semi-revolution. Now here is a known cause, operating just like the attraction of external bodies in the solar system, and producing just such an effect. Thus, again, we have an instance, in which a mechanical experiment, that can be performed in

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*In Fig. 11, the globe, suspended from the ceiling, and drawn aside, is urged by a component of gravity towards G, where it would hang, if at rest. Being thrown obliquely so as to describe the ellipse in the direction of the *single-shaft* arrows, it will, at its successive returns, pass through the points A, B, C, D, &c. The *double-shaft* arrows show this motion of the apsides to be in the direction in which the globe describes its orbit; that is, the *apsides advance.*

the lecture-room, and a great fact in astronomy, are explained on the same principles.

If there were but *two* bodies in the system, their mutual orbits would be undisturbed. Some conic section would be exactly and forever described by each about their common centre of gravity. But the introduction of a *third* body disturbs both these orbits, and its own is disturbed by them. In the solar system, therefore, in which hundreds of bodies are attracting each other, the disturbances are almost numberless; though multitudes of them are too minute to be perceived. The two which have now been noticed—namely, the retrogradation of nodes, and the advance of apsides—are among the most prominent. And though in some instances they are exceedingly minute, they at length become apparent, because they go on accumulating for ages instead of oscillating back and forth. The equinoxes, though they have an oscillatory inequality in their motion, are yet perpetually *receding* on the ecliptic, and must continue to do so while the earth exists. And the apsides, in like manner, are always moving *forward* in the same direction in which the planet moves.

It is worthy of notice, that while the mutual attractions of the planets *disturb* the orbits, they do not *derange* them. When the learner first considers the fact, that the sun and moon are perpetually pressing the equator of the earth towards the ecliptic, he is almost compelled to infer that it will be brought nearer and still nearer, until at length the two planes will coincide, and all distinction of seasons will disappear in every latitude of the earth. The sun will always culminate vertically at the equator; at the poles he will always be seen circulating about the horizon. But this calamitous derangement never can occur; the revolution on the axis prevents it. The combination of the *two* movements is, as we have seen, a simple retrocession of the equinoxes, which involves no change in the succession of seasons.

So, too, when the student of astronomy learns that the outer planets draw the earth away from the sun most of all at the aphelion, where it is already at the greatest distance, he seems to see this aphelion distance becoming greater and greater, as ages pass on, and the perihelion, of necessity, during the same ages, drawing nearer and nearer (as I move this ball in more and more eccentric ellipses about the lamp) until the condition of the earth's climate becomes fatal to every living thing. At the perihelion, the earth is subjected to an intolerable heat; at the aphelion, to a cold equally intolerable. But calculation and experiment both show, that the aphelion point, instead of being *removed from the sun*, by the attractions of the outer planets, will simply *slide around*, keeping its *distance* from the sun the same as ever. The planets have too much stability to be seriously deranged in respect to their orbits by the influence of outsiders.

This preservation of safe relations among the planets, in the midst of unceasing changes and disturbances, is one of the most interesting facts presented to the mind of the pupil in astronomy. He who *made* the countless spheres, ordained the laws of their motion; and those laws, by their perfect operation, secure the utmost peace and harmony, though worlds, thousands of miles in diameter, are rushing through space with a velocity which it is fearful to contemplate. Huge as are these masses of matter, and terrific as are their velocities, they are perfectly controlled by their Omnipotent Lord, who subjects them to those few and simple laws with which we all have to do in the actions of every-day life.

[Since the delivery, in January last, of this ingenious and interesting lecture, the motions of the rotascope or gyrascope, as it is now called, has unexpectedly become a subject of general popular interest, and thousands of copies of a simple form of the instrument are now manufactured to gratify the public curiosity. The explanation of the principles of compound rotary motion is as old as the day of Newton, and the experimental illustrations given in this lecture have been annually exhibited by Professor Snell to his class in Amherst College for upwards of twenty years.

The following remarks may, perhaps, serve to make the brief explanation of Professor Snell of the horizontal rotation a little more easily understood. Suppose the horizontal axes (fig. 10) placed north and south, and the wheel revolving towards the east, then the particle A will tend to move eastward by the rotation and northward by the action of gravity; the resultant will therefore fall between these two directions, but much nearer the former, on account of the greater force. The tendency will therefore be to turn the plane of the disk outward, which, on account of the fixed position of the point B, must carry the point D backwards. The same statement may be made with regard to the motion of the lower point of the disk, which conspires with the upper to produce a motion of the system in the same direction.

An interesting application of the principle of compound rotation has lately been made to the explanation of the lateral deviation of a ball from a rifle-bore cannon. The deviation is always in the same direction, and is the result of the same kind of action which produces the horizontal rotation of the system exhibited in the experiment (fig. 10) of the lecture. J. H.]

METEOROLOGY.

ABSTRACT OF OBSERVATIONS MADE DURING THE YEARS 1853, 1854, AND 1855, AT SACRAMENTO, CALIFORNIA.

BY THOMAS M. LOGAN, M. D.

GENERAL REMARKS.

The following observations and tables have been carefully drawn up and verified for future comparative reference. As the initiative of a series of more comprehensive and perfect observations, which it is proposed to prosecute for several successive years, they are now presented for record among the reports of the Smithsonian Institution. The increasing rigor which advancing physical science exacts before generalizations can be reliably deduced, especially requires the adoption of such a course, in a new country like this, possessed as it is of one of the most extraordinary climates known. In frequent instances discrepancies will be found between the present tables and those published in the reports for 1854, originating in errors of copy and typography, and which are now corrected. The barometric and thermometric computations are the result of three daily observations. Prior to April, 1854, they were made at 8 a. m., 3 p. m., and 10 p. m.; since that date, at sunrise, 3 p. m., and 10 p. m. Henceforth they will be continued, in accordance with the uniform system of observation adopted by the Smithsonian Institution, at 7 a. m., 2 p. m., and 9 p. m. The course of the wind was also noted three times a day, corresponding with the above periods, as well as the state of the weather in relation to clearness, cloudiness, and rain. By clear days, is meant *entirely clear—i. e.*, no clouds whatever being visible at the time of observation; by cloudy, that some clouds were visible when it did not rain; and by rainy days, that more or less rain then fell without reference to quantity. The dew-point was taken at the driest time of the day only, (3 p. m.,) from July, 1854, to November, 1855, with Daniels' hygrometer; since then, it has been calculated from three daily observations with the wet and dry-bulb thermometer. The three tables of hourly observations for twenty-four successive hours, are the first of a series to be repeated four times every year, at or about the period of the solstices and equinoxes, for the purpose of determining the corrections to be applied, in order to render comparable with each other, the records made at different periods of the day. It will be perceived, in these "term observations," that the horary oscillations of the barometer present in a marked degree the two diurnal maxima and minima which obtain within the tropics. From a register kept with an extremely sensitive open-cistern barometer for six months, from the 1st of April, 1855, to September following, inclusive, for the express purpose of testing the regularity of the ebb and flow of the ærial ocean, it is ascertained that the mean monthly range between the sunrise and the 9½ a. m. readings, amounted to 1.07 inch *plus*, in favor of the latter hour; whereas, between the 3 p. m. and the 9½ p. m. readings, the mean monthly range was only 0.46 inch *plus*, in favor of the last hour. These observations will be continued for six months longer, in order to determine whether the fluctuations of atmospheric pressure occur as regularly in the same ratio and degree during the rainy season. The instruments employed were all placed in the open air on the north side of the lower story of a brick building, in a sheltered projection, and protected against the effect of either direct or reflected insolation, as well as against nocturnal radiation. In consequence of the care exercised in this respect, the figures of the thermometer ranged generally lower during the summer than those of other observers in the city. It is necessary to add, before proceeding to the special remarks for each year, that, according to recent observations by the Aneroid barometer, the altitude of the city may be put down at thirty-nine feet above tide-level. The latitude is 38° 34′ 42″ north, and the longitude 121° 40′ 05″ west.

REMARKS FOR 1853.

With the exception of the winter of 1849–'50, which, according to the representations of those who then resided here, was a season of almost continual rain-storms, that of 1852–'53 ranks thus far as the most notable for its high winds and heavy rains. The high northwest wind which set in a few days after the great fire in November, 1852, was succeeded by deluging rains, accompanied with strong wind from the southeast. The Sacramento river, which drains about 15,000 square miles before reaching the city, rose above its natural banks higher than was ever before known, converting the streets of Sacramento into flowing streams and bottomless quagmires. On the 1st of January the city was totally submerged. Dense fogs prevailed during the greater part of the days of the 3d, 4th, 13th, 14th, 17th, 18th, 19th, 20th, 21st, and 22d, which, in connexion with the predominance of southerly winds and the frequent fall of rain, caused a degree of humidity amounting almost constantly to saturation. February was comparatively a dry month. On the 5th the streets of Sacramento began to be passable, and in many points manifested indications of desiccation; while the river fell steadily, notwithstanding the rains towards the latter part of the month. On the night of the 22d there was a rain-storm from the southeast; after which date it rained more or less until the 25th, when it blew a gale from the southeast, with heavy rain at night. By the 6th of March the Sacramento river had fallen unusually low for the season, and the streets of the city, thus thoroughly drained, were drying up rapidly under the influence of a hot sun—the thermometer at 3 p. m. reading 75°. On the 8th heavy rains commenced falling again, and the weather continued variable to the end of the month. Nothing worthy of note occurred at the date of the equinox; but on the 28th, one of the heaviest rains ever measured here was found to have fallen, amounting to about five inches. On the following day the Sacramento river was found to have risen twelve feet in twenty-four hours, overflowing its natural banks, and cutting off all communication with the interior by stages. On the 31st the American river, which empties into the Sacramento on the north side of the city, fell four feet in twenty-four hours; but the height of the Sacramento river remained unchanged, having attained within three inches of being as high as it was on the 1st of January.

April 1.—The river commenced backing up through a break in the levee at Sutterville, about two miles south of the city, and continued to rise at the rate of one inch per hour until the streets were again overflowed on the morning of the 2d. On the 4th heavy warm rains from the south commenced falling; the weather became genial, and vegetation began to burst forth. Notwithstanding the river began to fall slowly and steadily, it was still kept high by these spring showers. On the 13th, during a heavy shower from the south, vivid flashes of lightning, followed quickly by thunder, were witnessed; which phenomena also occurred on the 17th and 29th. At the latter date the rain was ushered in by a sprinkle of hail from a nimboid-cumulus from the southeast. The severest storm of the season occurred on the night of the 16th, the wind blowing a gale from the southeast, accompanied by rain.

May was unusually boisterous; high winds prevailing frequently from the south and southwest. The last shower of the regular rainy season occurred on the 20th. There was afterwards a sprinkle on the 28th and 29th. At the close of the month the river was within a few inches of the top of its natural banks, and still falling very slowly.

June was the hottest month in the year, and was generally so throughout the State. On the 19th the barometer fell to the minimum of the month, lower than it was ever known, with the wind strong from the southeast. This uncommon disturbance of the equilibrium of the atmosphere was followed by no other appreciable effects here than a considerable moderation of temperature, and a brisk shower of rain on the 26th; an unusual occurrence in June. The mean temperature was 80° when the sun entered Cancer, and the mean reading of the barometer was 29.25 inches: weather clear, and wind veering from south to northwest.

July was rendered most agreeable by a greater proportion of relative moisture in the atmosphere than is usually found during midsummer, and which may be attributed to the prevalence of southeast winds. Two sprinkles of rain—one on the 17th and the other on the 21st—occurred this month. That on the 17th happened about sunset, when a beautiful rainbow was refracted.

August was characterized by remarkably cool nights. The minima observed on the nights of the 13th and 31st were 51° and 50° respectively.

September was comparatively a sultry month; the wind being generally very light, particularly during the last four days. A brisk shower of rain occurred at daylight on the 15th, with the wind from southwest, and the barometer reading 29.90 inches. On the 22d, the mean reading of the barometer was 30.05 inches, and of the thermometer 74°: sky clear, and wind southerly and light.

October opened with calm sultry weather, which continued during the first six days; afterwards it became variable. The first rain of the season fell before daylight on the 10th. During the last half of the month the wind prevailed strong from the northwest, and on the last three days it was very high.

On the 4th of November the regular rainy season may be said to have set in, although the quantity of rain that fell did not amount to more than about an inch and a half for the whole month.

December was throughout a cold month. Hoar frosts were frequent and vegetation was completely arrested. There were eight foggy days this month; two entirely so. On two afternoons these fogs gravitated towards the earth in the form of mist; generally, however, they were dissipated before noon. At the period of the winter solstice rain fell, and the thermometer sank to 32° at sunrise; the wind blowing fresh from southeast, and the barometer reading 30 inches. The year ended cold and clear, with the wind from northwest.

Our tables for 1853 are not as complete as we could have desired, because we were not provided in time with the necessary meteorological appliances; and, consequently, the monthly quantitative fall of rain cannot be put down with scientific accuracy. The annual amount, however, recorded in the table, approximates very nearly, the true measurement.

REMARKS FOR 1854.

The opening month of this year is notable for its unprecedented low temperature. For the first five days the mornings were foggy, the wind remaining all the time very light from northwest. On the morning of the 5th the barometer fell suddenly 0.30 inch, and in the afternoon a gale set in from the northwest and blew violently for twenty-four hours. On the next morning, Sutter lake, situated at the northwest angle of the city, was frozen over, and the thermometer at 8 a. m. read 32°. From this date to the 20th the weather was variable. The rains were cold and generally accompanied with high wind from southeast. On the 15th the Coast range* of mountains presented the novel appearance of being covered with snow in their whole extent, and on the 20th the thermometer fell to the lowest point ever before observed since the settlement of the country, viz: 19° at 7 a. m., and did not rise above freezing the whole day. So persistent was the cold that Sutter lake remained frozen over for twenty-four successive hours. The mean temperature for four days, from the 19th to the 23d, was 29°. From all the information that can be obtained from the oldest settlers, the greatest degree of cold previously observed was in December, 1850, when the thermometer fell to 26°.

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* The Sierra Nevada lie parallel to the coast of the Pacific, and, as their name imports, this lofty range of mountains is always more or less capped with snow. But between the latitudes 34° and 41°—between San Buenaventura and the Bay of Trinidad—there runs west of the Sierra another smaller chain called the Coast range, of which Monte del Diablo, 3,760 feet, Mount Ripley, 7,500 feet, and Mount St. John, 8,000 feet high, according to Milleson, are the culminating points. In the valley between this Coast range and the Great Sierra, varying in breadth from 40 to 80 miles, according to Fremont, flow from the south the river San Joaquin, and from the north the Sacramento.

February was the most rainy month thus far observed, both as regards the quantity that fell and the number of rainy days. On the 28th there was a considerable sprinkle of hail, attended with lightning and thunder, from a nimbus coursing from west to east.

March was stormy, high winds prevailing from almost every point of the compass. Most of the rain that fell this month was on the 13th, 14th, and 15th, the wind veering about and blowing, at one time, strong from the northeast, which is unusual. Immediately after this the Sacramento river, which had remained at a very low stage all the winter, commenced rising suddenly and soon reached twenty feet two inches above low-water mark. It soon, however, began to fall again. When the sun entered Aries the weather was fine and clear; wind northwest; mean temperature 61°; mean reading of barometer 30.16 inches. On the 30th a comet was visible in the western horizon at about 8 p. m. It bore northwest by north, with an altitude of about 20°; length of tail about 6°, extending towards the zenith.

April, although preceded by the coldest winter yet observed, was, from its inception, literally the opening month, and towards its latter end vegetation was as much advanced as at the corresponding period of the previous year. A coincidence worthy of note, inasmuch as these phenomena are so seldom witnessed, was the occurrence of lightning and thunder on the 29th of the same month last year as well as at the same date this year, accompanied by hail from a nimbus coursing southeast; the mean reading of the barometer on the latter date being 29.90 inches, and of the thermometer 60.03°.

May was characterized by capricious weather, vacillating between winter and summer. Two more thunder-storms, attended with high wind, occurred, one on the 6th and the other on the 18th. The former, though less severe in the neighborhood of the city than that of the 29th April, seemed to spend its chief fury, accompanied with hail, in its course from southwest, extending from a point about eight miles from the city to an unascertained distance beyond. This storm, which lasted fifteen minutes, was so severe at a place called Spanish Ranch, in the American valley, that the inmates were obliged to barricade the windows and doors to prevent them being blown in, and two of a herd of cattle were killed by lightning. The barometer did not read lower here at the time than thirty inches. The great annular eclipse of the sun was well observed here on the 26th, the sky being entirely cloudless. At the period of the greatest obscuration the landscape presented the same appearance as when viewed through glasses of a neutral tint, and totally different from the shades of evening. The sky was of the deep greenish blue color seen in some paintings of the Venetian school. On the following day the wind, which had been fresh from the south, changed to southwest, and then to northwest, from which quarter it blew a gale from 10 a. m., for twenty-four hours. After this it moderated a little, but continued high to the last day of the month, when the barometer fell to its extraordinary minimum, as in table No. 2.

June responded from the very first to the atmospheric disturbances of the preceding month, and the established natural laws of the dry season were infringed three different times by rain, on the 1st, 12th, and 17th. The rain on the 12th was accompanied by lightning and distant thunder, but that on the 17th was the heaviest, measuring 0.20 inch. Although June is regarded as one of the dry months, still we find, in a journal of one of our pioneers, that "it poured during the night of the 11th June, 1849," and, as is seen in the tables, it has rained a little in this month every year. The wind was high about the period of the solstice, but the barometer did not fall below thirty inches at that date.

July was remarkable as being the hottest month yet observed. At 3 p. m. of the 13th, for the first time since we have been keeping a meteorological register, the several thermometers distributed in various parts of the lower story of our brick residence marked 100° and upwards, and remained at that height until 5 p. m. One placed near the door of the southern front, and somewhat exposed to the effect of reflected insolation, although ten feet from the sunshine, rose to 107°: In several wooden buildings through which the solar heat penetrated and accumulated, the mercury was seen by us as high as 110° ; but this is not so high as apparent when we take into consideration the fact that the atmosphere here is always filled in the summer season with particles of dust and sand, which form, as Humboldt says, "centres of radiant heat." All these observations were made, although to the windward, still near the locality of the great fire which occurred about 3 p. m. on the 13th. Now, as the 12th, 13th, and 14th were the three hottest days, and the mercury did not rise higher than 98° on the first, and 99° on the last of these days, it is not unphilosophical to attribute the solitary instance of extreme heat to the dryness of the atmosphere, artificially increased by the conflagration, and which measured 42° by the thermometer of Daniells' hygrometer. And such an inference is sustained by the fact that on the 13th the wind was from the southwest, which is much cooler and moister than that of northwest, which prevailed on the 12th and 14th. The mean temperature of the hottest part of the day for the week ending July 15th, was 97°. During the last half of the month the weather moderated considerably, showing a difference of about 8° between the mean maximum temperature of the first and last half.

August was characterized by the usual atmospheric changes which usher in the autumnal season. The night of the 16th was the hottest night as yet noticed in the country, the thermometer standing at 82° at 10 p. m., and 70° at sunrise. On the 17th the barometer commenced falling, and continued to do so until it reached the minimum of the month. This variation of the usual atmospheric pressure was attended with fresh breezes from southeast, and followed by a slight shower of rain on the morning of the 21st. After this the weather became suddenly cool, the nights being quite chilly, with the thermometer ranging from 54° to 60°. During this month the Sacramento river fell to the lowest point ever known since the settlement of the country.

In September little worthy of remark is recorded. On the 14th, at 10 p. m., frequent flashes of lightning were observed in the northeast. The equinox passed away without any other atmospheric disturbance than a slight sprinkle of rain at daylight ; wind southwest, fresh ; barometer 30.08 inches, and thermometer at 58°.

During October, indications of the setting in of the rainy season were developed. Although the quantity of rain that actually fell was small, still the proportion of moisture in the atmosphere was large for this locality and season—the dew point having been generally only 8 or 10° below the temperature of the air; whereas during the preceding summer months the freedom from watery vapor, as measured by the thermometers of the psychrometer, ranged from 20° to 30°.

Our record for November shows the most agreeable weather, the genial effects of which were manifested in the verdure of the fields and fruitfulness of the gardens. In the neighborhood of the city, strawberries ripened on flourishing plants, and green peas were in such a state of forwardness as to justify the expectation of their being ready for market at Christmas.

December, another rainy month, passed away without much prospect of our getting the usual semi-annual allowance of rain. From the 4th to the 9th the fogs were so dense during the earlier part of the day as to measure in the aggregate 0.07 inch by the rain-gage. The first killing frost of the season occurred on the 9th. The sun entered Capricornus during fine and clear weather. The year closed with a strong gale and rain from southeast, which measured 0.60 inch; the barometer reading 29.78 inches, and the thermometer 54°.

REMARKS FOR 1855.

The new year was ushered in with a violent rain-storm, veering from southeast to southwest. The barometer at sunrise stood at 29.38 inches, and the thermometer at 51°. The quantity of rain that fell before 8 p. m., measured 1.12 inches. By the next morning the weather was clear, with the wind fresh from north; the temperature at freezing-point, and barometer at 30 inches. After this, only a little rain fell occasionally; but from the 10th to the 20th, the densest fogs and mists prevailed continuously, measuring in the aggregate, by the rain-gage, 0.16 inch. Sometimes the ascending current would for an hour or two, during the warmest part of the day, carry off the vapor with it; but the wind, which was for the most part warm, and from southeast, was too light to prevent the re-precipitation of the excess of moisture in the air. On the 5th and 14th there was a slight fall of snow, which unusual phenomenon was also witnessed two winters ago, at Brighton, about four miles to the eastward. The month closed with pleasant weather, and the verdure of the plains presented indications of an early spring.

February was characterized by the variable meteorological phenomena usually attendant upon the breaking up of winter and the opening of spring. During the first half of the month the weather was generally pleasant and genial. On the 1st, the cowslip was observed in profuse blossom all over the surrounding plains; also, on the 15th, the wild violet; on the 20th, the peach tree, and on the 23d, the pond willow, (*Salix nigra*,) and the nemophilla, a small indigenous blue flower. At daylight on the 24th, the thermometer fell suddenly to the freezing-point at Sutter's Fort, the wind being fresh from north-northwest. The next day the wind changed to the southward, from which quarter it continued to prevail almost constantly to the end of the month, accompanied for the most part with a steady, warm rain. For several days preceding the copious rains, during the latter part of the month, the atmospheric pressure appeared subjected to powerful disturbing influences, the barometric column sinking to the minimum for the month, as stated in the table, on the 19th. The weather all the while remaining clear, with high wind from northwest, and a comparatively anhydrous condition of the atmosphere, seemed to conflict with the barometric indications of approaching rain. The heaviest rain of the season commenced falling at noon on the 27th, and continued without interruption until 10 p. m. of the 28th, when the barometer rose suddenly one-tenth of an inch, and the clouds began to break away. The quantity of rain that fell during these twenty-four hours measured 2.10 inches.

March was noted for the comparative infrequency of high winds and rain-storms. The vernal equinox was attended with no appreciable atmospheric disturbance; the weather remaining mild, equable, and pleasant. The thermometer, however, ranged rather higher than usual for the season. The deficiency of rain during the winter months was measurably made up by frequent heavy spring showers, which served to melt and bring down the snow from the mountains. On the 15th the Sacramento river, which had remained at a very low stage all the winter, rose to 20 feet 2½ inches above low-water mark; which was within 1 foot 9 inches of the high-water mark of 1st January, 1853. During the two last days of the month a steady, warm rain fell, beginning about 8 p. m. of the 29th, and continuing almost without interruption until 9 a. m. of the 31st, when it commenced blowing a gale from the south, with occasional heavy showers. At the same time the barometric column sank to the minimum for the month, but began to rise again before evening, when the gale abated. On the afternoon of the 27th, at 5 o'clock, a remarkable iridescence, globular in form, and which may be termed a parhelion, was observed at the western termination of a cloud in the southwest, about 45° above the horizon. The beautiful prismatic tinting of this meteor, which lasted about one or two minutes, was the subject of general admiration and newspaper remark.

In April the weather was very changeable, and more snow fell on the mountains than is recollected to have fallen so late in the season since 1849. The coincidence, remarked last April, of the unusual occurrence of lightning and thunder on the same day of the previous year, was rendered still more remarkable by the recurrence of the same phenomenon on the 14th of this month. The barometric as well as all other changes were sudden and frequent. The minimum recorded in the table occurred on the 15th, the maximum on the 18th. The maximum of the thermometer was observed on the 8th, the minimum on the 18th; after which latter date a varying temperature, with a comparative excess of humidity and southerly winds, predominated.

The most noticeable feature in May consisted in the recurrence, so infrequent in this region, of electric phenomena on two occasions, (the

10th and the 14th,) which happened likewise on the 6th and 18th of the corresponding month last year, as well as on the 14th of the preceding month this year. Nothing, however, in the way of thunderstorms was ever witnessed here like the dense nimbus which suddenly arose from the southwest at about 3 p. m. on the 14th, and discharged its watery contents, to the amount of 0.80 inch of rain, over the city, rivalling, in the vivid shocks of its well charged battery, the violent thunder-gusts of more tropical regions. As appears in the table, considerable rain for the season fell, being an overplus of 0.94 inch above that of May, 1854, although minus 0.10 inch of what fell in May, 1853. During the whole month the barometer ranged uniformly low, and maintained a greater equability in its oscillations than was observed for some months previously. With the exception of the 29th, 30th, and 31st, the thermometer indicated an agreeable temperature, while a sufficiency of relative moisture in the atmosphere rendered the weather pleasant and salutary. On these last days, however, the afternoons were oppressively sultry, in consequence of the wind being light from northwest all day, and dying away towards evening. These few uncomfortable days were more than compensated for by delicious and refreshing nights, "when the heavens seemed to unfold the brightest page of their mystic lore." Indeed, no possible combination of the great agents of nature in producing an agreeable climate can surpass the delightful moonlight nights of Sacramento, when fanned by the balmy breathings of the south, fresh from the Pacific.

June was characterized by one of those extraordinary oscillations of temperature which occasionally occur early in the summer in every part of the North American continent, and which have been found to return on an average of every ten or twelve years at several stations where observations have been made through a series of years. On the 21st the thermometer rose to 100°, and on the 22d in many places beyond that point. This elevation of the temperature to 100°, at the period of the solstice, appears to be not more extraordinary for Sacramento than for other places at the same parallel of latitude. Richmond and Washington, isothermally considered, many miles north of Sacramento, are likewise occasionally subject, the former to a maximum temperature of 102° and the latter 100°, during the month of June. The condition of the atmospheric pressure was also peculiar. During the earlier part of the month the barometric column sank to the minimum, as recorded in the table, without any other appreciable sequence than some increase in the relative humidity of the atmosphere. During the whole month it maintained a more or less low position, except on the 11th and 12th, when it rose nearly as high as at any other time during the month, although on these very days we were visited with light showers of rain from the south. On the 25th the barometer fell again as low as it did in the earlier part of the month, when the wind commenced blowing fresh from the south, and afterwards, on the 28th, changed to the northwest. The effect of such hot weather, so early in the season, proved disastrous to the agricultural interests, by developing the eggs of the grasshopper—a species of *gryllidæ*—six weeks earlier than they were hatched out the year previous. There is no animal that multiplies so fast as these, if the sun be hot, and the soil in which the eggs are deposited be dry; and it is apprehended, for these reasons, that these destructive insects may reappear whenever the hot weather sets in early.

July presented a most favorable specimen of our summer climate, as if in compensation for the excessive solstitial heat of the preceding month. There was scarcely a day in which the air was not refrigerated by southerly breezes. The barometer ranged persistently low, and the atmospheric disturbance, indicated by its sinking to the minimum on the 14th, was followed by accounts of showers of rain in various parts of the surrounding country from Yreka to San Francisco. There was no rain at this point, but an increase of the humidity of the atmosphere was manifested on several occasions by the formation of clouds, and on the 18th vivid flashes of lightning were witnessed in the eastern horizon.

In August there predominated a comparatively large proportion of the relative humidity of the atmosphere, accompanied by an almost constant prevalence of southerly winds, and a persistently low range of the barometer. These phenomena were followed in some parts of the State by early rains. In Nevada, Sierra, Butte, and Plumas, heavy showers were reported to have fallen on the 19th. At the same date it was cloudy here, and the relative moisture at the driest time of the day amounted to 50 per cent. of saturation.

In September the first rains of the season occurred antecedent to the equinox. After the prevalence of a high wind for twelve hours, attended with flitting clouds from the southwest, a nimbus passed over the city about sunset on the 15th, dropping an almost imperceptible sprinkle, and displaying a beautiful iris in the northeast. A heavy bank of clouds was then seen to settle over the Sierra Nevada, occasionally giving forth flashes of lightning. On the next evening, the wind still prevailing from the same quarter, we were visited by a shower sufficient to clear the atmosphere of dust for a short time. Again on the following evening a heavy nimbus was seen to pass from west-southwest to southeast, emitting vivid flashes of lightning, followed by audible thunder. Prior to these occurrences the barometer manifested considerable perturbation; sinking to the minimum on the 10th, and ranging generally low during the whole month. During the latter part of the month was experienced somewhat of the sultry, stagnant condition of the atmosphere which is peculiar to the season when the wind is light from the northwest.

October furnished further indications of the advent of the rainy season. The relative moisture of the atmosphere had been for some time gradually augmenting in per-centage, when, on the morning of the 29th, saturation manifested itself in the mist that prevailed until 10 a. m. The greatest degree of humidity previously observed was on the 24th, the day of the eclipse of the moon, when the relative moisture at the driest time of the day was 67 per cent., and the absolute humidity 6.07 grains in each cubic foot. During the whole time of the lunar obscuration the atmosphere was transparently clear, and the phenomenon was seen perfectly through its progress; the thermometer ranging from 63° at *9h. 34m.* p. m., to 55° at *1h. 5m.* a. m.;

the barometer reading at the same time 30.04 inches, with the wind light from the northwest.

In November the large proportion of aqueous vapor which had been accumulating for some time previously, was condensed by the high wind from northwest, which prevailed strong during the first five days, and during one day, the 3d, very high. While this natural operation was going on, the evolution of electricity was satisfactorily demonstrated by the magnetic telegraph, the wires serving to collect and conduct off some of the abounding electricity of the air. On the 2d, the battery at Marysville was detached, and the communication preserved without its agency. On the following morning thin ice was seen at daylight on a neighboring farm, and the potato, watermelon vines, and okra showed in their blackened leaves the effects of the first frost. Cloudy weather, with southerly winds, soon succeeded, and on the night of the 9th the rain came. On the 10th frequent flashes of lightning were observed about 11½ p. m. in the northern horizon. After four days of occasional light rains, the weather cleared up, and light northerly winds prevailed until the 21st, when the barometer fell suddenly from 30 to 29.80 inches, the minimum for the month, with the wind fresh from southwest. This variation of atmospheric pressure was ascertained by means of the telegraph to be simultaneous at various points, from Downieville to San Francisco. At the latter place a light rain commenced falling on the same evening, while at the same period a remarkable corona of three concentric rings of different colors, pale red, blue, and white, close to the moon, was observed in this city, revealing the presence of rain, or rather sleet, in the higher regions of the atmosphere. Before the succeeding morning a sprinkle reached us, which was followed up in the evening by a steady light rain, with a fresh breeze from southeast, until 9 a. m. of the 24th, measuring 0.235 inch. After this the wind changed to the dry quarter, northwest, but was too light to disperse the evaporation which was precipitated in the air during the night, and on the morning of the 25th a dense fog prevailed until the ascending current, at 11 a. m., carried off the vapor with it. On the following day the breeze came fresh from northwest, and the barometer reached its maximum for the month. After this the weather became variable. On the 28th a light rain fell from 10 a. m. to 1 p. m., measuring 0.123 inch; and again, on the 30th, another little shower, from 4 to 6 p. m., measuring 0.024 inch. The mean relative humidity for the month was sixty-four per cent. The phenomena incidental to December in the north temperate zone, of decreasing days, gloomy fogs, saturating rains, piercing winds, and chilling frosts, concluded the train of the departing year; fulfilling, in the order of their recurrence, the laws which were put in force by the Creator, when the foundations of the earth were laid. Although the month opened fair, the weather manifested, by a sprinkle at 12 m. on the 2d, symptoms of variableness, which obtained until the 7th, when the heaviest rain of the season, from southeast, fell between the hours of 1 and 4½ p. m., measuring 0.610 inch. On the night previously, at about 10½ p. m., there was a slight fall of snow, just sufficient to make the phenomenon apparent. It was of short duration, and was followed immediately by a light shower of rain. From this date to the 24th there were only two days entirely clear, thirteen cloudy and rainy, and two foggy days. The quantity of rain which fell in the aggregate during this interval amounted to 0.672 inch.

Notwithstanding this long continuance of unsettled weather which prevailed generally throughout the interior of the State, the atmospheric pressure at the same period manifested no unusual disturbance—the barometer never falling below 30 inches, and, indeed, reading as low as that point only twice, and for a short time: once on the 6th, when it snowed, and again when the sun entered Capricornus. In the table of hourly observations at this latter period will be noted the gradually progressive rise and fall of both barometer and thermometer during the twenty-four hours. At 9 a. m. the temperature was three degrees lower than at 4 a. m., while the atmospheric pressure was .03 of an inch, increased by the veering of the wind to the westward. At 10 a. m. the sky appeared almost entirely clear, but by 3 p. m. it became almost entirely cloudy, although the wind had increased in force from the west. At 10 p. m. a large halo of the moon was observed, consisting of a single luminous circle of about 45° diameter; and again at 2 p. m., when the sky had become almost entirely cloudless, a corona of three faint concentric rings, apparently about 5° in diameter, encircled the moon. Notwithstanding these indications of the surcharge of the upper regions of the atmosphere with humidity, the wind freshened up from northwest in the afternoon, and by 9 p. m. the sky was entirely clear. Before morning the thermometer fell to the extraordinary minimum of 25°, and the barometer rose to 30.08 inches. On the succeeding day the sky was entirely overcast, and although the lower current of air continued fresh from northwest, the rising of the barometer from 30 to 30.12 inches, under such circumstances, indicated some unusual pressure of the atmosphere. As the sequence demonstrated, this barometric oscillation was attributable to the marginal accumulation of air around the storm, which was heralded on the morning of the 26th by an unprecedented fall of snow, the lower current of air still prevailing light from the north. Simultaneously a rapid diminution of atmospheric pressure was manifested, and by 10 p. m. it was blowing a gale from southeast, the rain, which had been falling all day, now coming with gusts, from low clouds driven before it. At 7 a. m. on the 27th, when the storm had reached its terminal point in this quarter, the barometer sank to its minimum, 29.78 inches, and the thermometer read 49°. At 9 p. m. following, the barometer had attained its ordinary altitude of 30 inches, and the temperature was six degrees less than at the sunrise observation, while the sky was almost entirely clear, with the breeze fresh from northwest. The snow-storm lasted from 6 to 10 a. m., and the quantity that fell amounted to 0.016 inch when melted and measured by the rain-gage. The aggregate of melted snow and rain which fell from 6 a. m. of the 26th to 10 a. m. of the 27th, measured 0.725 inch. The effect of the rains thus far upon the river was to raise it about 30 inches above low-water mark. Accounts from the interior represent the fall of snow as very great, and, consequently, the river may not be much affected thereby until the warm rains of spring.

From the 27th to the close of the month the weather remained clear and cold, with the wind steady from north and northwest, with the exception of a part of the day of the 30th, when it veered to east and northeast, the barometer nearly all the time remaining stationary at about 30.15 inches, and never attaining the maximum it previously reached on the 9th, 13th, 14th, 16th, and 17th. The mean temperature of the four last cold days of the month was 34°, being 5° plus the mean temperature of the four coldest days, from the 19th to the 23d January, 1854. The mean of all the highest readings of the thermometer by day was 56.04°, and of all the lowest by night 44.03°: the mean daily range of temperature during the month was, therefore, 12.01°. The mean degree of humidity was 0.818, complete saturation being represented by 1,000.

Abstract of Meteorological Observations, made during the years 1853, 1854, *and* 1855, *at Sacramento, California, by Thomas M. Logan, M. D.*

COMPARATIVE TABLE, No. 1.

Barometer, thermometer, and dew-point.	January.	Febru'y.	March.	April.	May.	June.	July.	August.	Septem'r	October.	Novem'r	Decem'r.	Mean.
1853.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
Barometer.....Maximum.	30.23	30.39	30.42	30.38	30.28	30.20	30.20	30.05	30.10	30.40	30.45	30.45	30.29
Minimum.	29.60	29.63	29.95	29.88	29.88	28.98	29.95	29.85	29.90	29.90	29.30	29.70	29.71
Mean.....	29.65	30.06	30.10	30.13	30.09	29.79	30.06	30.03	29.95	30.15	30.05	30.13	30.01
	°	°	°	°	°	°	°	°	°	°	°	°	°
Thermometer..Maximum.	66	68	75	76	78	97	93	93	95	88	72	64	80.40
Minimum.	33	38	46	50	54	58	62	58	54	58	46	32	49
Mean.....	43	50	50.80	61	68	77	75	71	76	78	53	48	62.15
1854.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
Barometer.....Maximum.	30.45	30.40	30.40	30.45	30.28	30.22	30.13	30.20	30.20	30.20	30.35	30.32	30.30
Minimum.	29.70	29.70	29.85	29.85	29	29.90	29.85	29.80	29.85	29.83	30.05	29.75	29.76
Mean.....	29.11	30.17	30.05	30.04	30.02	30.03	30.08	30.05	30.04	30.13	30.21	29.94	29.98
	°	°	°	°	°	°	°	°	°	°	°	°	°
Thermometer..Maximum.	59	62	68	75	77	90	101.50	99	90	90	72	68	79.54
Minimum.	19	38	37	49	48	49	50.75	52	48	49	44	29	42.72
Mean.....	43	51	53	60	62	67	80.63	69.47	65.05	60.01	55.05	47.93	59.51
Dew-point.....Maximum.	--------	--------	--------	--------	--------	--------	68	62.50	55	55	49.50	49	56.50
Minimum.	--------	--------	--------	--------	--------	--------	45.50	43	40.50	32	34	25.50	36.74
Mean.....	--------	--------	--------	--------	--------	--------	61.59	50.22	48.20	45.40	42.65	39	47.84

COMPARATIVE TABLE No. 1—Continued.

Barometer, thermometer, and dew-point.	January.	Febru'y.	March.	April.	May.	June.	July.	August.	Septem'r	October.	Novem'r	Decem'r.	Mean.
1855.													
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
Barometer.....Maximum.	30.41	30.23	30.11	30.19	30.09	30.10	29.85	29.88	29.85	30.14	30.30	30.20	30.09
Minimum.	29.38	29.57	29.59	29.57	29.65	29.59	29.59	29.54	29.65	29.85	29.80	29.78	29.63
Mean.....	30.20	30.03	29.97	30.13	30.06	29.83	29.98	29.74	29.72	30	30.04	30.08	29.98
	°	°	°	°	°	°	°	°	°	°	°	°	°
Thermometer..Maximum.	62	70	76	81	90	100	99	98	94	93	69	59	82.58
Minimum.	27	32	41	41	44	52	58	60	54	45	34	25	42.75
Mean.....	43.71	52.50	54.82	58.06	60.20	71.10	72.55	73.04	68.01	63.01	50.65	45.99	59.47
Dew-point.....Maximum.	44.50	51.50	59	57	60	69	60	66	56.56	57	56	52	57.38
Minimum.	30	18	32	36.50	32	42	48	46	41	46	32	15	34.87
Mean.....	38.08	41.37	45.13	46	47.10	56.06	50.80	55.50	47.55	51.50	42.22	38.92	47.52

REMARKS.—The dew-point was taken at the driest time of the day only, (3 p. m.,) from July, 1854, to November, 1855, with Daniells' hygrometer; since then it has been calculated from three daily observations with the wet and dry bulb thermometers.

COMPARATIVE TABLE, No. 2.

Weather—rain and wind.	January.	Febru'y.	March.	April.	May.	June.	July.	August.	Septem'r	October.	Novem'r	Decem'r.	Total.
1853.													
Number of days clear	7	19	16	16	19	27	25	22	28	26	13	21	239
Number of days cloudy	12	3	7	7	6	2	2	9	1	4	11	6	70
Number of days rainy	12	6	8	7	6	1	4	--------	1	1	6	4	56
Number of inches of rain	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	20.00
Number of days N. wind	2	2	1	3	2	3	--------	--------	--------	1	--------	2	16
Number of days N. W. wind	9	16	11	8	7	13	4	1	9	23	13	16	130
Number of days W wind	--------	--------	--------	1	--------	--------	--------	--------	--------	1	--------	1	3
Number of days S. W. wind	4	3	10	7	10	7	2	3	5	3	4	2	60
Number of days S. wind	2	2	--------	3	4	4	1	2	4	1	5	2	30
Number of days S. E. wind	13	5	9	7	7	3	24	25	9	2	5	2	101
Number of days E. wind	1	--------	--------	1	1	--------	--------	--------	1	--------	3	2	9
Number of days N. E. wind	--------	--------	--------	--------	--------	--------	--------	--------	2	--------	--------	4	6
1854.													
Number of days clear	19	10	18	9	23	20	27	25	26	12	20	19	223
Number of days cloudy	5	6	9	12	4	7	4	5	3	10	8	9	82
Number of days rainy	7	12	9	9	4	3	--------	1	1	9	2	3	60
Number of inches of rain	3.25	8.50	8.25	1.50	0.21	0.31	--------	Sprinkle	Sprinkle	1.01	0.65	1.15	19.83
Number of days N. wind	4	3	4	1	1	⅓	2⅔	⅔	1⅔	2⅓	6⅔	3	30⅓
Number of days N. W. wind	16	8	8	10	6	6	4	2⅓	2	7⅔	12⅔	17⅔	100⅓
Number of days W. wind	1	1	2	1	1	⅓	11⅓	1	3⅓	⅔	1⅓	⅓	24⅓
Number of days S. W. wind	1	1	5	8	8⅓	7⅔	7⅔	8	10⅓	8	3⅓	--------	68⅓
Number of days S. wind	3	1	8	5	8⅔	10	5	3	5	3⅓	--------	1	58
Number of days S. E. wind	5	6	1	3	3⅔	3⅔	--------	10⅔	7	7⅔	2⅓	4⅓	54⅓
Number of days E. wind	--------	4	1	⅓	1⅓	1	--------	⅓	⅔	⅓	1	3	13
Number of days N. E. wind	1	4	2	1⅔	1	1	⅓	--------	--------	1	2⅔	1⅔	16⅓

COMPARATIVE TABLE No. 2.—Continued.

Weather—rain and wind.	January.	Febru'y.	March.	April.	May.	June.	July.	August.	Septem'r	October.	Novem'r	Decem'r.	Total.
1855.													
Number of days clear	8	16	10	8	16	26	22	26	21	17	12	10	192
Number of days cloudy	18	3	13	14	9	2	9	5	7	14	11	8	113
Number of days rainy	5	9	8	8	6	2	--------	--------	2	--------	7	13	60
Number of inches of rain	2. 67	3. 46	4. 20	4. 32	1. 15	0. 01	--------	--------	Sprinkle	--------	0. 75	2. 00	18. 56
Number of days N. wind	2⅔	4⅓	2	2	--------	⅔	--------	--------	⅔	1	7	4½	24⅔
Number of days N.W. wind	13	10	10⅔	8⅓	8⅔	5	2⅓	2⅓	10	10⅔	7	9⅓	97⅓
Number of days W. wind	⅓	--------	1	1	1	1⅓	--------	⅓	⅓	1	⅔	2⅔	9⅔
Number of days S. W. wind	3	5	5	8⅓	11	6⅓	9⅓	8⅔	7⅔	10⅓	4⅓	11⅔	90⅔
Number of days S. wind	1⅔	2	3⅔	3⅓	4⅔	6⅔	11	9	4	1⅓	1	1⅓	49⅔
Number of days S. E. wind	6⅓	6	8	6	5⅔	10	8⅓	10⅔	7	6	6	⅔	80⅔
Number of days E. wind	1⅓	⅓	⅓	⅔	--------	--------	--------	--------	--------	⅔	1⅓	⅔	5⅓
Number of days N. E. wind	2⅔	⅓	⅓	⅓	--------	--------	--------	--------	⅓	--------	2⅔	⅓	7

Remarks.—By clear days is meant entirely clear—*i. e.*, no clouds whatever being visible; and by rainy days, that more or less rain fell, without reference to quantity. Not being provided in time with a suitable pluviometer, the monthly quantitative fall of rain for 1853 cannot be put down with scientific accuracy. The annual amount recorded approximates very nearly the true measurement.

TABLE No. 3.

Observations for twenty-four successive hours, taken on the 19*th of June*, 1855.

Hour.	Barometer.	Thermometer.	Clouds, their course and velocity.	Wind, direction and force.	Dew-point.	Relative humidity.
	Inches.	°			°	
4 a. m	29.97	62		S. E. 1	56	.838
5 a. m	29.97	63		S. E. 1	54	.761
6 a. m	29.97	65		S. E. 1	52	.668
7 a. m	29.97	68		S. E. 1	51	.592
8 a. m	29.97	70		S. E. 1	50	.540
9 a. m	29.98	71		S. E. 1	51	.541
10 a. m	29.98	76		S. E. 1	51	.463
11 a. m	29.97	79		S. E. 1	52	.438
12 m	29.97	84		S. W. 2	50	.356
1 p. m	29.96	85		S. W. 2	50	.346
2 p. m	29.94	86		S. W. 2	50	.336
3 p. m	29.95	88		S. W. 2	50	.318
4 p. m	29.93	87		S. W. 2	50	.326
5 p. m	29.93	85		S. W. 2	49	.336
6 p. m	29.93	82		S. W. 1	49	.367
7 p. m	29.93	79		S. W. 1	48	.387
8 p. m	29.96	74		S. E. 1	48	.451
9 p. m	29.96	72		S. E. 1	46	.450
10 p. m	29.95	70		S. E. 1	45	.463
11 p. m	29.94	68		S. E. 1	46	.509
12 p. m	29.95	67		S. E. 1	48	.558
1 a. m	29.95	66		S. E. 1	49	.591
2 a. m	29.94	65		S. E. 1	52	.668
3 a. m	29.93	62		S. E. 1	54	.786
4 a. m	29.94	61		S. E. 1	56	.861

REMARKS.—The mean temperature of the 22d, the period of our summer solstice, was so much beyond the average, it is deemed best to record the hourly observations made on the 19th, as most useful for purposes of comparison and correction.

The departure of the mean temperature of the 19th from that of the 22d June, 1854, was 1.50 degrees *minus*. The mean temperature of the corresponding day last year, (the 19th,) was the same as that of this year.

The reading of the barometer varied only 0.01 inch from the average of three years on the 22d June. The wind of the corresponding day in 1854 prevailed from N.W., light; sky clear. In 1853 the wind was fresh from the S., and sky more or less invested with cirri-strati.

[From the foregoing table, it appears that on this day the maximum temperature occurred at 3 p. m., and the minimum at 4 a. m. The maximum of humidity was at 4 a. m., and the minimum at 3 p. m.; and since the wind continued light during the day, these results are probably the same as those which would be obtained from the observations during a number of days. The barometer exhibits two maxima and two minima, but the points at which these occur are not precisely marked.]

TABLE No. 4.

Observations for twenty-four successive hours, taken on the 22d *of September*, 1855.

Hour.	Barometer.	Thermometer.	Clouds, their course and velocity.	Wind, direction and force.	Dew-point.	Relative humidity.
	Inches.	°			°	
4 a. m	29.90	54	2—S. W. 1	S. 1	48	.827
5 a. m	29.89	54	2—S. W. 1	S. E. 1	47	.802
6 a. m	29.86	56	2—S. W. 1	S. E. 3	46	.729
7 a. m	29.88	56	2—S. W. 1	S. W. 3	45	.706
8 a. m	29.90	59	1—S. W. 1	S. W. 3	43	.600
9 a. m	29.92	61	1—S. W. 1	S. W. 3	45	.608
10 a. m	29.93	65	1—S. W. 1	S. W. 1	47	.574
11 a. m	29.90	66	1—S. W. 1	S. W. 1	48	.574
12 m	29.89	68	1—S. W. 1	S. 1	49	.557
1 p. m	29.90	69	1—S. W. 1	S. E. 2	46	.494
2 p. m	29.90	72	1—S. W. 1	S. 1	49	.493
3 p. m	29.90	73	1—S. W. 1	S. 1	48	.465
4 p. m	29.92	72	0	S. 1	48	.479
5 p. m	29.93	70	0	S. 1	50	.540
6 p. m	29.93	67	0	S. 1	52	.630
7 p. m	29.92	66	0	S. 1	52	.648
8 p. m	29.92	64	0	S. 2	45	.555
9 p. m	29.92	62	0	S. 3	43	.552
10 p. m	29.93	58	0	S. 3	45	.663
11 p. m	29.93	57	0	S. 3	48	.753
12 p. m	29.92	56	0	S. 3	48	.776
1 a. m	29.92	55	0	S. 3	49	.824
2 a. m	29.93	55	0	S 3	50	.848
3 a. m	29.94	54	0	S. 2	50	.876
4 a. m	29.94	54	0	S. 1	52	.934

REMARKS.—The departure of the mean daily temperature from the average of the same day for three years was 7.01° *minus*.

The reading of the barometer varied 0.18 inch *minus* from that of the same day last year, and 0.13 inch *minus* from that of the 22d September, 1853.

The wind of the corresponding day last year prevailed from S. W. fresh; and although there was a slight sprinkle at daylight on the same day, the sky was clear for the remainder. On the 22d September, 1853, the wind was high from the N. W., and sky entirely clear.

TABLE No. 5.

Observations for twenty-four successive hours, taken on the 22d of December, 1855.

Hour.	Barometer.	Thermometer.	Clouds, their course and velocity.	Wind, direction and force.	Dew-point.	Relative humidity.
	Inches.	°			°	
4 a. m.	30	55	10—$\frac{\text{S. E. 2}}{\text{S. W. 4}}$	S. W. 4	51	.876
5 a. m.	30	55	2	S. W. 2	51	.876
6 a. m.	30	54	5—S. E. 1	S. W. 1	49	.880
7 a. m.	30	53	4—E. 1	S. 1	47	.886
8 a. m.	30.02	51	3—S. E. 1	S. E. 2	46	.887
9 a. m.	30.03	52	3—W. 2.	W. S. W. 2	47	.886
10 a. m.	30.04	53	1	W. N. W. 2	45	.805
11 a. m.	30.04	54	2	W. N. W. 2	44	.752
12 m.	30.04	55	8—$\frac{\text{S.E.1}}{\text{W.N.W.2}}$	W. N. W. 2	44	.752
1 p. m.	30.03	55	7—W.N.W.2	N. W. 3	40	.626
2 p. m.	30.02	54	5—W.N.W.1	N. N. W. 3	39	.630
3 p. m.	30.02	55	9—W. 4	N. N. W. 2	36	.559
4 p. m.	30.02	54	8—W. 2	N. N. W. 2	39	.630
5 p. m.	30.02	53	7—W. 1	N. N. W 2	39	.630
6 p. m.	30.02	52	8—W. 1	N. N. W. 2	44	.803
7 p. m.	30.02	51	8—W. 1	W. 2	43	.801
8 p. m.	30.02	49	5—W. 2	N. W. 2	41	.781
9 p. m.	30.03	48	4—W. 2	N. W. 2	40	.780
10 p. m.	30.03	47	3—W. 3	N. W. 2	39	.781
11 p. m.	30.03	45	2—W. 4	N. W. 3	36	.768
12 p. m.	30.03	44	1	N. W. 3	35	.772
1 a. m.	30.03	43	1	N. W. 3	32	.725
2 a. m.	30.02	42	1	N. W. 3	34	.838
3 a. m.	30.01	41	1	N. W. 3	33	.834
4 a. m.	30	41	1	N. W. 3	33	.834

REMARKS.—From 6 p. m. of the 20th to 7 p. m. of the 21st it rained, with brief intermissions, to the amount of 0.268 inch, with the wind light from S. E., and remained cloudy up to the hour the present observations were commenced. On the corresponding day in 1853 the weather was clear, with the wind fresh from N. W.; the mean temperature on the same day being 44°, and the mean reading of the barometer 30.15 inches.

At 10 p. m. of the 23d the sky was entirely covered with cumulo-stratified clouds; and by 9 p. m. entirely clear, with the wind strong from N. W.

On the morning of the 24th, the thermometer fell to 25°; and on the morning of the 26th the unprecedented fall of snow occurred.

METEOROLOGY.

REMARKS

ON THE

QUANTITY OF RAIN AT DIFFERENT HEIGHTS.

BY PROFESSOR O. W. MORRIS, OF NEW YORK.

At a meeting of the Lyceum of Natural History of New York in 1846, and at the meeting of the American Association for the Advancement of Science, at Albany, in 1851, some account was given of the quantity of rain at different heights, with the hope that some other observers would, from the few hints given, take up the subject, and furnish some more definite information than was yet known, especially in this country; but nothing has yet fallen under my observation. Absence from the State, and other causes, hindered me from prosecuting the inquiry till 1854, when a gage, such as is used by the observers of the Smithsonian Institution, was placed on the observatory of the Institution for the Deaf and Dumb, in New York city, and a similar one on the surface of the ground; the upper one eighty-five feet above the lower.

From observations with these instruments, it has been ascertained that the difference in quantity depends upon a variety of circumstances; for the quantity is generally increased in a sudden thunder-shower, or violent wind; while with but little wind or a moist atmosphere preceding the rain, the difference is slight. Thus, in twelve thunder-storms which occurred in twelve months, the lower gage afforded 8.33 inches, and the upper 5.35 inches, showing a difference of 1.98 inches; while in twelve storms which occurred with light winds or none at all, the lower gage afforded 4.75 inches, and the upper 4.05 inches, showing a difference of only 0.70 of an inch.

With a moist atmosphere preceding seventeen storms, some of them long, the lower gage afforded 11.73 inches, the upper 7.97, a difference of 3.76 inches; and with a dry atmosphere preceding the storm, thirty-eight storms afforded in the lower gage 31.37 inches, and the upper 23.13 inches, showing a difference of 8.24 inches. In the first instance the average difference for each storm was about 0.21 inch; in the latter, it was 0.22 inch. It would therefore seem that whenever there is much disturbance by winds, &c., there is less ability in the vapor to rise to any considerable height, owing, in part, to the increased weight of the falling fluid; or else there is a more rapid condensation of the vapor at the surface of the earth, which agrees with the theory of Mr. Russell.

Whether this theory be the true one or not, there is much plausibility in it, and in many cases it is applicable, while in a few it fails to apply, especially in long-continued rains.

A satisfactory theory has yet to be established, and the facts that have been, and are now collecting, will serve to suggest some important rules on this branch of meteorology.

If proper meteorological apparatus could be procured, carefully watched, and the facts noted by a sufficient number of observers at proper distances from each other, correct comparisons might be instituted, and data furnished for establishing fixed principles to guide the student of nature in his search for truth; but in this country the state of society and the circumstances of most of those who would engage in the enterprise debar them from its successful pursuit. It can only be carried on by the aid of government, or the liberality of the wealthy. When either of these is given, then will meteorology in our country make itself known and felt by its beneficial results to society; and not the least among these will be such as follow the investigation of the laws governing the precipitation of water from the atmosphere.

With the apparatus mentioned above, the following results have been obtained; premising, however, that during the months of winter no record of the difference was kept, as the drifting of the snow and other causes rendered the observations not reliable. A record was kept of the direction of the wind, the height of the mercury in the dry and wet bulb thermometers, with the relative humidity and force of vapor, the duration of the rain-storms, as well as the quantity of water collected in each gage. To note all these circumstances in this paper would make it too long, and be interesting to only a few; therefore the aggregate results for each *month* will be mentioned.

Number of storms.		Prevailing wind.	Quantity.		Difference.
			Upper gage.	Lower gage.	Lower, +
1854.			*Inches.*	*Inches.*	*Inches.*
April	6	Easterly	2.703	3.82	1.117
May	6	do	3.12	4.28	1.16
June	7	do	1.68	2.29	0.61
July	2	do	2.20	2.72	0.52
August	2	do	3.20	4.15	0.95
October	4	do	1.67	2.65	0.98
November	4	Westerly	2.81	4.33	1.52
1855.					
April	6	do	2.42	2.86	0.44
May	3	Easterly	3.50	4.90	1.40
June	8	do	4.10	5.83	1.73
July	7	do	3.44	5.46	2.02
August	4	do	2.06	2.90	0.84
Mean	5		2.742	3.85	1.107

NOTE.—Difference in height 85 feet.

These means are for twelve (not consecutive) months—the prevailing wind being Easterly.

The greatest monthly difference was in July, 1855, when it was 2.02 inches; the greatest in any one storm was in November, 1854, a difference of 1.18 inches; the storm was of about twenty-two hours' continuance, and the wind west. The least monthly difference was in April, 1855—0.44 inch; and the least in any one storm was in July, 1855—0.02 inch. The storm was about twelve hours' duration, and the wind northeast, and light; the air on the previous day was damp, and but little wind. The quantity for the six cooler months was 26.22 inches in the upper, and 22.94 in the lower gage, showing a difference of 6.72 inches. The quantity for the six warmer months was 16.69 inches in the upper, and 23.35 inches in the lower, a difference of 6.66 inches, showing a difference of only 0.06 inch between the warm and cool months. There were seventeen storms in which the atmosphere preceding their commencement was moist, when the difference was 3.76 inches; and thirty-eight storms in which it was dry, with a difference of 8.24 inches. The difference in thirteen thunder-showers was 2.98 inches, in a quantity of 5.35 inches in the upper, and 8.33 inches in the lower; and in a quantity of 4.05 inches in the upper, and 4.75 inches in the lower, there was a difference of 0.70 inch, when there was little or no wind. The general result for the twelve months is 32.90 inches in the upper, and 46.29 inches in the lower gage, a difference of 13.39 inches. Of the storms, thirty of them occurred with the wind easterly, and the difference in quantity was 6.98 inches; eleven of them, with westerly winds, with a difference of 1.40 inches; nine, with the wind varying from west to east, and *vice versa*, with a difference of 2.60 inches; two, with south wind, and a difference of 0.21 inch; four, with a gale from northeast, with a difference of 2.01. and one varying from southwest to northeast, and a difference of 0.86 inch. The greatest difference for the time of continuance was in one of about forty-five minutes' duration, with but little wind, when it was 0.37 inch in 1.28 in quantity; the wind was west.

These facts are thrown out for the consideration of observers, in the hope that some system may be adopted by which more accurate observations will be secured.

REMARKS BY THE SECRETARY OF THE SMITHSONIAN INSTITUTION.

The subject of the difference of rain at different elevations has received much attention in this country and in Europe; though more investigations are required to settle definitely all the principles on which it depends. It would appear that the greater part of the observed difference is due to eddies of wind, which carry the air containing the falling drops more rapidly over the mouth of the upper gage than it would pass over an equal portion of the unobstructed surface of the ground. Professor Bache found, from a series of observations on the top and at the bottom of a shot-tower in Philadelphia, that not only was there a difference due to elevation, but also to the position of the upper gage, whether it was placed on the windward or leeward side of the tower. It would also appear, that when the air is saturated with moisture down to the surface of the earth, the descending drop would collect at least a portion of the water it meets with in its passage to the ground, but the amount thus collected would not be sufficient to account for the difference observed. Besides this, the condition does not always exist; the air near the earth is frequently undersaturated during rain, and in this case a portion of the drop would be evaporated, and its size on reaching the earth less than it was above. If the drop is increased by the deposition of new vapor in its descent, then the rain at the bottom ought to be warmer than at the top, on account of the latent heat evolved in the condensation; on the other hand, if the drop be diminished by evaporization during its fall, then the temperature of the rain caught at the greater elevation ought to be in excess. That evaporization does sometimes take place during the fall of rain, would appear from the fact that clouds are seen to exhibit the appearance of giving out rain though none falls to the earth, the whole being entirely evaporated. That the air should ever be undersaturated during rain is at first sight a very surprising fact; it may, however, be accounted for on the principle of capillarity. The attraction of the surface of a spherical portion of water for itself is in proportion to the curvature or the smallness of the quantity, and hence the tendency to evaporate in a rain-drop ought to be much less than in an equal portion of a flat surface of water.

If the diminution of quantity of rain at the upper station depends principally on eddies of wind, then the effect will be diminished by an increase in the size of the drops, which will give them a greater power of resistance; and the size of the drop will probably be influenced by the intensity of the electricity of the air, as well as by its dryness. The former, as well as the latter, will tend to increase the evaporation from the surface of the drop.

It is a well-established fact, which at first sight would appear to be at variance with the results of observations on towers, that a greater amount of rain falls in some cases on high mountains than on the adjacent plains. For example, the amount of water which annually falls at the convent of St. Bernard is very nearly double that which falls at Geneva. This effect, however, is due to the south wind, loaded with moisture, ascending the slope of the mountain into a colder region, which causes a precipitation of its vapor. From what is here said, it will be evident that the subject of rain is one which involves many considerations, and which still presents a wide field for investigation.

A series of observations have been commenced at this Institution on the quantities of rain at different elevations, as well as on gages of different sizes and forms, the result of which will be given in one of the subsequent reports.

METEOROLOGY.

DIRECTIONS

FOR

METEOROLOGICAL OBSERVATIONS,

ADOPTED BY THE SMITHSONIAN INSTITUTION, FOR THE FIRST CLASS OF OBSERVERS.

The following directions were originally drawn up for the use of the observers in correspondence with the Smithsonian Institution, by Professor GUYOT, of the College of New Jersey, Princeton, and are now reprinted, with a series of additions, for more general distribution. The additions are indicated by brackets, [ ].

SECRETARY S. I.

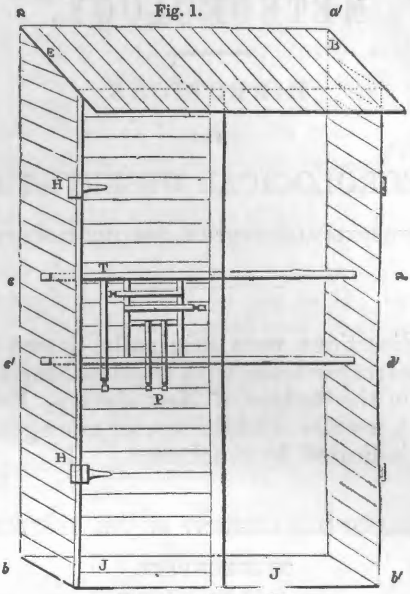
PLACING AND MANAGEMENT OF THE INSTRUMENTS.

THERMOMETER.

Placing.—Place the thermometer in the open air, and in an open space, out of the vicinity of high buildings, or of any obstacle that impedes the free circulation of the air. It should be so situated as to face the north, to be always in the shade, and be at least from nine to twelve inches from the walls of the building, and from every other neighboring object. The height from the ground may be from ten to fifteen feet, and, as far as possible, it should be the same at all the stations. The instrument should be protected against its own radiation to the sky, and against the light reflected by neighboring objects, such as buildings, the ground itself, and sheltered from the rain, snow, and hail. The following arrangement will fulfil these requirements, (figure 1.)

Select a window situated in the first story, fronting the north, in a room not heated or inhabited; remove the lattice blinds, if there be any, and along the exterior jambs of the window place perpendicularly two pieces of board, (*a b—a' b'*), projecting to a distance of from twenty to twenty-four inches from the panes. At half this distance, ten or twelve inches from the panes, and at the height of the eye of the observer, when in the chamber, pass from one piece of board to the other two small wooden transverse bars, (*c d, c' d'*,) each an inch broad, for the purpose of supporting the instruments. Upon the outer edge of the boards fasten in the usual way (H H) the latticed blinds which were removed from the jambs, or two others provided for the purpose. That blind, behind which the instruments are to be placed, is to serve as a screen, and must be fastened, almost entirely closed, so as make a little more opening; the other will remain entirely open to allow a free access of air and light, and is not to be closed except in great storms. The whole must be covered with a small inclined roof of board, (B E,) placed at least fifteen or twenty inches above the instrument. The lower part, (J J,) or the basis, may remain open.

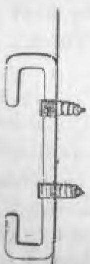
Fig. 1.



View from the outside.

[The foregoing is a convenient arrangement by which the observations can be taken without exposing the observer to the weather. To insure greater accuracy the windows during the intervals of observations may be closed with a wooden shutter. The outside of the lattice work should be painted white, to reflect off the light and heat which may fall upon it.]

Fig. 2.



The thermometer must be placed exactly perpendicular, the middle of the scale being at the height of the eye against the two small wooden bars, so that the top of the scale being fixed by a screw to the upper bar, the bulb may pass at least two or three inches beyond the lower bar. The instrument is attached to the last by a little metallic clasp. (Fig. 2.) It will thus be placed ten or twelve inches from the panes, from the screen, and the other parts of the window.

[In a later arrangement, a single transverse bar is used. This being placed at the necessary height, the thermometers are attached to it by small metal brackets, which support them at a distance from the bar of about two inches. The metal brackets are permanently screwed to the bar, and the thermometers are fastened to them by small finger-screws, by which they can be detached at pleasure. The order of placing them is shown in the cut.]

Reading.—To read the thermometer, the eye must be placed exactly at the same height as the column of mercury. Unless this precaution is taken, there is a liability to errors, the greater in proportion to the thickness of the glass of the stem and the shortness of the degrees. The reading should be made at all times, and especially in the winter, through the panes, and without opening the window; otherwise the temperature of the chamber will inevitably influence the thermometer in the open air. The degrees must be read, and the fractions carefully estimated in tenths of degrees. After having rapidly taken the observation, another should be made to verify it. If there are several other instruments to observe, and the thermometer is to be read first, the first reading may be made some minutes before the hour; the second, after the reading of the psychrometer; and if there is a difference, the mean number is to be entered in the journal. When, notwithstanding the shelter, the bulb of the thermometer is moistened by rain or fog, or covered with ice or snow, it is necessary to wipe it rapidly, and not to record the degree until the instrument has been allowed to acquire the true temperature of the air.

Verification.—Verify the zero point, at the beginning and end of winter. For this purpose, fill a vessel with snow, immerse the bulb of the thermometer in the middle of it, so as to be surrounded on every side by a layer of several inches of snow, slightly pressed around the instrument. The stem must be placed exactly perpendicular, and covered with snow as far up as the freezing-point on the scale. Let it stand so for half an hour or more, and then read it, taking great care to place the eye at the same height as the summit of the mercurial column. If the top of the column does not coïncide with the freezing-point of the scale, the exact amount of the difference must be ascertained, and the correction immediately applied. At the same time enter in the journal, under its appropriate head, the day on which the experiment is made, its quantity, and the moment at which the application of it was commenced. [It is necessary to add that since the zero point of the thermometer is not that of the temperature of snow as it is frequently found when exposed to the atmosphere, but that of melting snow, the experiment must be made in a place above the temperature of freezing. Instead of snow, pounded ice may be employed.]

[Green's thermometers have an arrangement by which the tube can be slipped down the small quantity necessary to correct for this change. The end of the tube is fitted into a small plate of German silver, and this fastened by a screw to the scale. If, on testing the thermometer, the mercury be found to stand above 32°, free the screw one or two turns without taking it out, and push down the plate the necessary amount to bring the mercury to coincide. The thermometer must be handled with great care in making this adjustment, and it may be well, for additional security against accident, to loosen all the screws which fasten the bands around the tube—it will then slide in them more freely. After completing the adjustment, they may again be set moderately tight. The object of this adjustment being only to avoid the trouble of making a correction, it is not advisable to attempt it, if the observer thinks that he risks, in so doing, the safety of his instrument. As the tubes of these standard thermometers are kept for a considerable time before fixing the zero point, in most cases the moving will not be required. After the first year the zero point changes little, and practically, when exposed only to atmospheric influences, may be considered permanent.]

SELF-REGISTERING THERMOMETERS.

Placing.—These two thermometers, indicating the maxima and minima, are to be placed beside the common thermometer, in a horizontal position, with the bulbs opposite and free, on two small perpendicular supports uniting the two bars, as shown in Fig. 1.

Reading.—For the reading, place the eye in such a position that the visual ray may be perpendicular to the extremity of the index; enter the indications with the fractions of degrees, if there are any, and, after having verified them again, bring back, by means of the magnet, the indexes of the two thermometers to the summit of their respective columns.

Verification.—Compare the indications of the two thermometers frequently, and especially the spirit thermometer, with those of the common thermometer; verify the zeros at least *twice a year*, and, if there is a difference, adjust the zero anew, if the instrument permits, to eliminate the correction, as has been stated above for the simple thermometer, or take this correction into account in the register.

[The maximum thermometer is subject to derangement by the mercury getting to the side of the steel index and wedging it fast. When such is the case, put the bulb in ice, if it is necessary to bring the mercurial column so low, or cool it sufficiently to get all the mercury down that will pass the index; then move the magnet along the tube with a slight knocking or jarring motion, and try to get the index into the chamber at the top of the stem. If you get the index free of the wedge, but with mercury above it, heat the bulb until all the disjointed mercury and index are driven into the chamber, then keep the index up by the magnet, and the mercury will go back as the bulb cools. The great point of attention is to get and keep the index free of the wedge. The mercury being above, is of little consequence, as it can readily be heated up into the chamber; in doing this, most watchfulness is required in not suffering the index to wedge by the driving mercury. If the index is so wedged that it cannot be moved by these methods, then take the thermometer steadily in the hand, and swing it quickly, as if you wished to throw the mercury into the chamber at the top; the index with more or less mercury will be found in the chamber: if not, repeat the swinging until it is there. Then heat up the bulb until the mercury joins that in the chamber, keep the index up by the magnet, and let the mercury by cooling go back in unbroken line.

In using the magnet to move the index up into contact with the mercury, care must be taken not to urge it too strongly, or it may *enter* the mercury.

In using the magnet with the spirit-thermometer, the same care is necessary as with the mercurial, as the index may be forced out of the spirit, entangling the vapor and the alcohol. When this is the case the thermometer must be taken down and held vertically—a few taps or jars will bring the spirit together. The spirit-thermometer requires attention, also, in this particular. The vapor above the spirit is apt, in time, to condense at the end of the tube, commonly at the very end. When the spirit-thermometer stands lower than the mercurial one, this may be suspected and looked for. When so found, the thermometer should be taken down and shaken until the alcohol runs down; it should then be kept in an upright position for some time to drain. If it is found difficult to *shake* down the condensed vapor, the end of the tube may be carefully and slowly heated with a small lamp, or a small rod of heated iron held at a short distance, keeping the bulb and lower part as cold as possible; the alcohol by vaporization will then condense at the surface of the spirit in connexion with the bulb. Occasionally, in cold climates, spirit-thermometers are deranged by the air absorbed by the alcohol becoming free in the bulb at a low temperature. When this occurs bring the thermometer to as low a temperature as may be convenient; then hold it in such a position that the air-bubble comes to the juncture of the bulb and tube, warm the bulb till all the air is in the tube, then by shaking the thermometer, or by gentle knocking, the spirit will flow down, and the air speck come to the top.

This does not occur in spirit thermometers that are closed with a vacuum, and the spirit at the time well freed from air. In this case, however, the above named difficulty from vaporization takes place more readily than when closed with air. These derangements of the spirit thermometer are readily rectified, and only require occasional examination to detect them.

Both the maximum and minimum thermometers may be adjusted without the magnet, by raising one end sufficiently to allow the index to slide down by its own weight.

The ordinary maximum thermometer (Rutherford's) not working well, even in the hands of many careful observers, has occasioned several attempts to make one without an index.

Mr. Green has lately contrived one. The object is effected by enclosing in the bulb a glass valve, which is floated by the mercury to the juncture of the bulb and tube. On an increase of heat the mercury from the bulb passes this valve, but on contraction from a decreasing temperature, the portion in the column is obstructed, and remains stationary, indicating the maximum point attained.

To set the instrument for another observation, it is held bulb downwards, and with a gentle jerk the mercury falls and joins that in the bulb; it is then placed horizontal in the usual way.

A movable valve-piece is introduced rather than a fixed obstruction or stricture, as in a new and ingenious maximum thermometer by Messrs. Negretti and Zambra, of London, in expectation that the observer will find greater ease and satisfaction in readjusting the instrument for observation.

Professor Phillips, of England, has also devised one. His plan is to cut off a portion of the column of mercury by an intervening small bubble of air. An increase of heat drives this detached portion forward, and leaves it there on a decrease of heat.

This form is also made by Mr. Green, and possesses some advantages peculiar to it; but, until experience decide otherwise, we doubt if it can be put in order after accidental derangement, by every observer. The former plans are not open to this objection.]

[NOTE.—These thermometers being new in plan, particular instructions in regard to suspending and setting them will be given with each instrument by the maker, Mr. James Green, New York.]

PSYCHROMETER.

Placing.—The psychrometer, or wet-bulb thermometer, must be situated under the same conditions as the thermometer. It should be placed on the same wooden bars, several inches off and outside of the thermometer. (See Fig. 1.)

The bulbs should also be entirely free, and at a distance from the bars.

In case of violent winds, the instrument may be sheltered by the movable blind, which may also serve as a fan to promote evaporation when the air is too still.

The cloth which surrounds the bulb ought to be of medium fineness, not too coarse; it should form a covering of equal thickness on all sides, and should not be drawn too closely upon the glass. Linen is preferable to cotton, which retains the dust. The covering should be changed every two or three months, and the bulb cleaned. [The linen may be washed without removal by means of a jet of clean water from a small syringe.]

Observation.—For the observation, take first a small vessel full of water, which should be left on the window, that the water may be at the temperature of the air; bring it near to the bulb, and immerse the bulb several times into the water. All the space between the bulb and the bottom of the scale must be wet, and care must be taken that the wrapping is thoroughly moistened, without, however, a too large drop remaining suspended at the bulb. The water used must be pure; the best is rain-water filtered, because it does not hold any salt in solution, which might incrust the cloth after evaporation.

[In some arrangements of the psychrometer the wet-bulb is kept constantly wet by conducting water to it from a small vessel, by capillary attraction, along a string of cotton wick. A series of comparative observations were made at this Institution last summer on these two modes of wetting the bulb, which gave the same result within a fraction of a degree from the mean of the records of a month. The observers connected with the Coast Survey prefer the method of dipping the covered bulb.]

After wetting the bulb, shut the window, and leave the psychrometer for a moment.

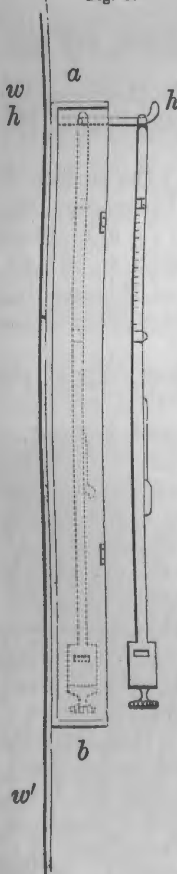
While the wet bulb is slowly acquiring the temperature of evaporation, the observer is occupied with other observations, watching the psychrometer to make sure of the moment when it has become stationary. In summer, from four to ten minutes are needed for this, according to the size of the bulb; but in winter, when the water freezes on the bulb, it must be moistened from fifteen to thirty minutes before the observation, which should not be made until the ice around the bulb is quite formed and dry. The best way is to keep round the bulb a layer of ice, constant and uniform, which should be neither too thick nor too thin; then the observation may take place immediately. When the temperature is in the neighborhood of the freezing-point, the observation of the psychrometer requires very peculiar care; the reason of which we have elsewhere explained. During a fog the wet-bulb thermometer may be somewhat higher than the dry-bulb; then the air is over-saturated, and contains, besides the vapor at its maximum of tension, water suspended in a disseminated liquid state.

If the air is very still, it is well to increase the evaporation by setting the air in motion by a fan. If the wind is too strong, the instrument should be protected by the movable blind. The reading must be made rapidly, and, as much as possible, at a distance, and without opening the window; for the proximity of the observer, either by the heat radiating from his body, or by his breath, as well as the temperature and the hygrometrical state of the air issuing from the chamber, which is always different from that of the external air, especially in winter, would infallibly act upon the instruments, and would falsify the observation.

Verification.—The two thermometers must be carefully compared from time to time, and if a difference is found, the instruments must be adjusted, or it must be taken into the account, and the observations corrected when entered in the journal.

BAROMETER.

Fig. 3.



Placing.—The barometer should be placed in a room, of a temperature as uniform as possible, not heated nor too much exposed to the sun. The instrument must be suspended at the height of the eye, near a window, in such a manner as to be lighted perfectly, without exposure either to the direct rays of the sun, or to the currents of the air, which always take place at the joinings of the windows. When the barometer has to be fixed to the wall, as is the case with all the common stationary and wheel barometers, care must be taken to secure the tube in a position perfectly vertical, regulating it by the plumb-line, first in front, then at the sides, at least in two vertical planes cutting each other at right angles. When the instrument is so constructed as to take its equilibrium itself, as the Fortin barometers and those of J. Green, recently made under the direction of the Smithsonian Institution, it is enough to hang it on a strong hook. These conditions being fulfilled, the rest of the arrangement may be varied according to the nature of the localities. For the Fortin and Green barometers, the following seems to be the most convenient, and may be almost everywhere adopted. (See Fig. 4.)

A small oblong box, (*a b*,) some inches longer than the barometer, and a little broader than its cistern, is firmly set against the wall, (*w w'*,) near the window, in such a manner as to open in a direction parallel to the panes; at the summit (*a*) it has a strong hook, (*h h'*,) which extends beyond the box about two or three inches, and on which the barometer is suspended. The instrument remains generally in the box, which is closed by a movable cover, and which protects it from external injuries, from dust, and from the direct radiation of the warm bodies, or the currents of air from the window, and diminishes the effect of the too sudden variations of temperature. When it is to be observed, the barometer is taken by the upper end of the tube, and the suspending ring is made to slide towards the end of the hook. The instrument is then in the full light of the window, in front of which the observer places himself; the summit of the mercurial column, as well as the surface of the mercury in the cistern, are completely lighted, and the reading becomes easy and certain. Moreover, the slight oscillating movement impressed on the instrument, by changing its place, breaks the adherence of the mercury to the glass, and thus prepares a good observation. After the reading, the barometer is again slipped gently into the box, and this is closed.

Observation.—The different operations of the barometer of constant level should be made in the following order:

a. Before all, incline the instrument gently, so as to render the mercurial column very movable; then, after having restored it to rest, strike several slight blows upon the casing, in such a manner as to impress on the mercury gentle vibrations. The adherence of the mercury to the glass will thus be destroyed, and the column will take its true equilibrium.

b. Note the degree and the tenths of degrees of the thermometer attached to the instrument; for it will be seen that the heat of the observer's body soon makes it rise.

c. Bring, by means of the adjusting screw, (Fig. 4,) the surface of the mercury to its constant level. In Green's first barometers, the metallic envelope of the cistern is pierced through, (*o o′*,) and allows the surface of the mercury contained in the glass cistern to be seen. The plane which passes through the upper edge (*e e′*) of this opening is the true level, or the *zero* of the scale, to which the surface of the mercury must be restored.

For this, take hold, with the left hand, of the lower edge of the cistern, (*l l′*,) taking great care not to disturb its vertical position; apply the right hand to the adjusting screw, (*s*,) and turning it gently, bring by degrees the level surface of the mercury to the upper edge (*e e′*) of the opening of the cistern, until there remains between the two only an almost imperceptible line of light, as in the Fig. 5, (*e e′*.) Then leave the instrument to itself to re-establish its verticality, if it had been accidentally deranged, and placing the eye exactly at the height of the mercury, examine whether the contact is exact. For this operation, it is important to have a good light; the cistern ought to be placed higher than the lower edge of the window, so that the light may reach it directly. It is necessary also to take care not to confound the slight line of light which marks the opposite edge of the cistern, with the light reflected by the surface of the mercury against the inner walls; the former is always sharp and well defined, the latter vague and indefinite. When, before adjusting the level, the mercury is higher than the upper edge, it is necessary to begin by lowering it beneath the level, (see Fig. 4,) so as to leave an interval of light, which is then gradually shut out, as has been described. When the observation is to be made in the night, place the lamp before, and not behind the instrument, and somewhat higher than the eye; and if the wall itself is not light enough, place behind the cistern, or the top of the column, a piece of white paper, which reflects the light.

Fig. 4.

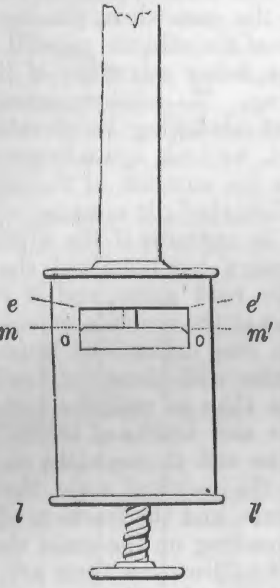
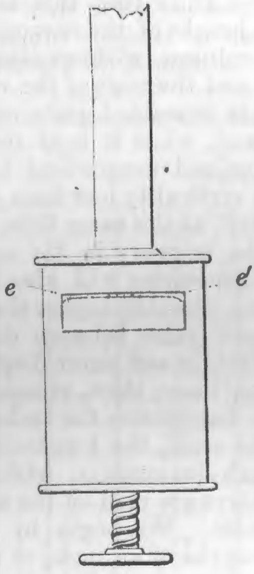


Fig. 5.



In the barometers with an ivory point, as the Fortin, Newman, and Green barometers, the extremity of this point is the zero of the scale, which must be brought into exact contact with the surface of the mercury. We commonly judge that this takes place when we see the actual rounded summit of the point coincide exactly with its image reflected below by the mercury. This method may be very good when the surface of the mercury is perfectly pure and brilliant; but this is very rare; it is generally dimmed by a slight layer of oxide, which makes the coincidence of the point with its image uncertain. It is safer to judge of the contact in a different manner. From the moment when the point does more than touch the surface, it forms around itself, by capillary action, a small depression, which, breaking the direction of the reflected rays, becomes immediately very easy to discover. It is enough, then, to raise the mercury so as slightly to immerse the point, then to lower it gradually until the little depression disappears. If care is taken to make a good light fall on that portion of the mercury which is under the point, and to use the aid of a magnifier, the adjustment of the point thus made, becomes not only easy, but very certain, and the errors to which we are liable are almost insensible, for they do not exceed two or three hundredths of a millimetre, or a thousandth of an inch.

d. The level being thus adjusted to the zero of the scale, we proceed to observe the height of the summit of the column. Take hold of the instrument with the left hand, above the attached thermometer, without moving it from the vertical; strike several slight blows in the neighborhood of the top of the column; then, by means of the screw lower the slide which carries the vernier, until the plane passing through the two lower opposite edges of it is exactly tangent to the summit of the *meniscus*—that is, the convexity which terminates the column. We know that this is the case when, placing the eye exactly at the height of the summit of the column, we still see the summit of the column, without there being any trace of light between the summit and the edge of the ring. To convince ourselves that the barometer has remained quite vertical during its operation, we leave it to itself, and, when it is at rest, we look again to see whether the ring has remained•tangentical to the summit of the column. If it has not, the verticality had been disturbed; it must be adjusted anew. It is necessary, at the same time, to examine if the adjustment of the surface of the mercury in the cistern has remained the same. The attached thermometer will also be read anew, and if it indicates a temperature noticeably higher than at the commencement of the observation, a mean value between the two indications must be adopted. An exact observer can never dispense with these verifications.

e. Nothing more, then, remains than to read the instrument. In the English barometers the inches and tenths of inches are read directly on the scale, the hundredths and thousandths on the vernier. In the French barometers, with the metrical scale, the centimetres and millimetres are read on the scale, and the fractions of millimetres on the vernier. We begin by reading on the scale the number of inches and tenths of an inch, or of millimetres, there are, as far up as the line which corresponds to the *lower* edge of the vernier, and which marks the summit of the column. In the Green barometers this line marks at the same time the zero of the vernier. If this line does not coincide with one of the divisions of the scale, we read the fraction of the following division on the vernier.

The principle of the vernier is very simple. If we wish to obtain tenths, we divide into ten parts a space on the vernier comprising nine parts of the scale, (see Fig. 6;) each division of the vernier is thus found shorter by a tenth than each division of the scale. Now, if we start from the point where the zero of the vernier and its tenth division coincide exactly with the first and the ninth division of the scale, and if we cause the vernier to move gradually from the ninth to the tenth division of the scale, we shall see the first, the second, the third, and the other divisions of the vernier as far as the tenth, coincide successively with one of the divisions of the scale. Now, the divisions of the scale to which those of the vernier correspond being equal parts, it follows that the space in question has been successively divided into ten parts, or tenths, by these successive coincidences. If the scale bears millimetres, the vernier will give tenths of millimetres; if it has tenths of an inch, the vernier will give hundredths. By changing the proportions, it may be made to indicate by the vernier smaller fractions, as twentieths of millimetres, or five hundredths of an inch, &c.

To read the vernier, we must look out for the line that coincides with one of the divisions of the scale; the number of this division of the vernier, proceeding from zero, indicates the number of tenths of millimetres, or of hundredths of an inch, which must be added to the whole number given by the scale. If none of the divisions of the scale coincides exactly, we estimate by the eye, in decimals, the quantity by which the vernier must be lowered to obtain a coincidence, and this is added to the fraction already obtained. This will be hundredths of millimetres in the metrical barometer, and thousandths of inches in the English barometers.

The following figures will serve as an example; the instrument is an English barometer.

Fig. 6.

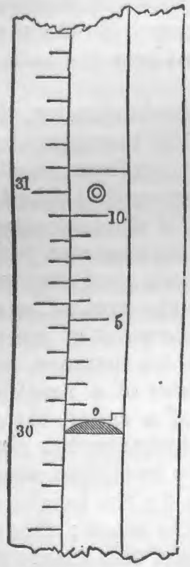


Fig. 7.

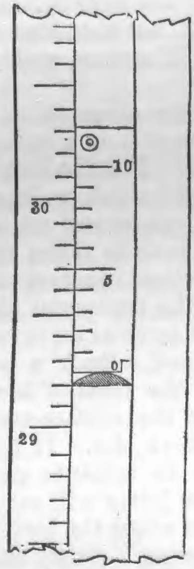
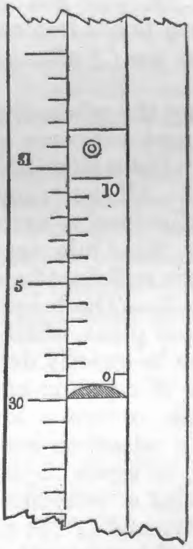


Fig. 8.



In Fig. 6 the regulating line, which is the lower edge of the vernier ring, coincides exactly with the line of thirty inches on the scale. The zero and the tenth division of the vernier are also in exact coincidence; that is to say, there is no fraction. We shall read then 30.000 inches.

In Fig. 7 the regulating line does not fall upon any of the divisions of the scale, but between twenty-nine inches and two-tenths and twenty-nine inches and three-tenths of inches. There is then a fraction which must be read on the vernier. Seeking which of these divisions coincides with that of the scale, we find that it is the fifth; we shall write then 29.250 inches.

In Fig. 8 we see that the height falls between thirty inches and thirty inches and one-tenth; no line of the vernier also coincides exactly; but the line 4 is a little above, the line 5 is a little below one of the lines of the scale; the fraction falls, then, between seven and eight hundredths. Estimating in tenths the distance the vernier passes over between the coincidence of seven and that of eight, we thus obtain the tenths of an hundredth, or the thousandths. In this latter case, the distance above seven is less than the half; we shall then read 30.073. It will always be easy to judge whether the top approaches nearer the upper coincidence than the lower coincidence; in the former case the fraction is greater than .005; in the latter it is smaller than .005. The error which will be committed in this estimate will remain less than .005; with practice and a little skill, it will hardly ever exceed .002, always supposing the scale is well graduated. For this reading, as well as for the others, it is particularly important to have the eye exactly at the height of the line to be determined.

The same process of reading is applied to the metrical scale; the vernier then gives tenths directly, and by estimate, the hundredths of millimetres. In the English instruments, the inches must be separated by a (.) and three decimals written, even when the last is a zero; *e. g.* 30.250, and not 30.25; the zero indicates that the thousandths have been taken into account, but that there is none. In the metrical scale put the (.) after the millimetres, and admit two decimals, *e. g.* 761.25.

During the whole time of the observation of the barometer, the observer must endeavor to protect it as much as possible from the heat which radiates from his body. But the best way is to learn to observe rapidly. All the operations of which we have just spoken take longer to describe than to execute; one or two minutes, if the instrument be in place, three minutes if it is to be taken from its case and put back again, are sufficient for a practised observer to make a good observation.

Altitude.—The height of the barometer above the ground, or above some fixed point, which may serve as an invariable point of reference, ought to be exactly determined. Such a point, for instance, may be the base of a public edifice, the level of low water of a neighboring river, the ordinary level of the surface-water of a canal, the upper part of a wharf in mason-work, &c. If the barometer has changed place, it is again necessary to measure exactly its height above the same point of reference; the latter will serve to fix the height of the barometer and of the station above the level of the ocean; this *datum* being of the greatest importance. Every change of this nature should be carefully noted in the journal.

It is greatly to be desired that the place of the barometer, once determined, should not be changed, either from one story to another, or from one house to another. If circumstances compel this to be done, we should begin, before taking it from its place, by raising the mercury in the cistern by means of the screw, so as to fill the cistern and the tube; it must then be gently taken from the hook, *turned upside down*, and carried with *the cistern up*, taking great care not to strike it against anything. If it were transported without these precautions, even from one chamber to another, great risk would infallibly be run of breaking it, or letting in air, and thus rendering it useless.

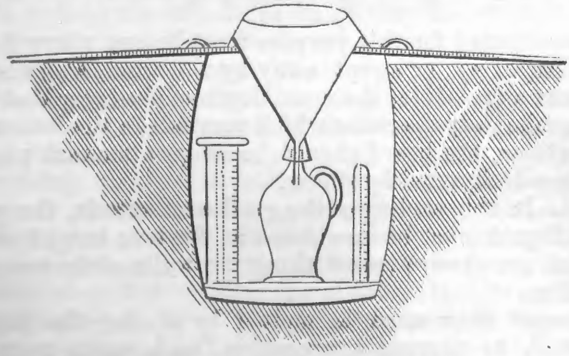
Verification.—From time to time the barometer should be so inclined as to cause the mercury to strike gently against the top of the tube. If it gives a dry and clear sound, it is free from air, and the instrument is in good condition. If the sound is flat and muffled, there is a little air in the barometric vacuum; and the fact should be noticed in the journal. Every occasion should be seized to compare it anew with a standard barometer, to ascertain whether it has undergone any change.

OMBROMETER.

Placing.—The *ombrometer*, or *rain-gage*, is a funnel, accompanied by a graduated cylindrical glass vessel, and by a reservoir. It should be placed in an open space. Trees, high buildings, and other obstacles, if too near, may have a considerable influence in increasing or diminishing the quantity of rain which falls into the funnel. The surface of the receiver should be placed horizontally about six inches above the ground. The most simple mode of establishing it is the following:

Place in the ground a cask or barrel, (Fig. 9,) water-tight, the top rising above the ground about three inches; cover it with boards slightly inclined in the form of a roof, which project on all sides beyond the edge of the barrel at least a foot. A circular opening in the middle receives the funnel, the borders of which rest on the board. At the bottom of the barrel, to receive the water, is an earthen or metallic vessel, with a narrow neck, (an ordinary earthen jug will answer,) in which is placed the end of the funnel, exactly filling the opening. It must contain two or three quarts. The funnel is fastened by means of two *clasps* to the board, which must be covered up with sod, to make it like the ground itself. If circumstances render it necessary to place the ombrometer higher, the height must be carefully noted in the journal. If it is placed upon a sloping roof, it should be on the top, and not at the edges, or at the angles, and must be raised several feet above the roof itself.

Fig. 9.



Observation.—To make the observation, remove the funnel, and pour the water from the jug into the large graduated glass cylinder. The opening of the funnel being one hundred square inches, one inch of rain in depth gives one hundred cubic inches of water; and each division of the glass containing a cubic inch of water, each of them represents a hundredth of an inch of rain fallen into the ombrometer. These degrees are large enough to permit us to estimate the thousandths of an inch. The divisions of the smaller graduated glass cylinder will measure directly the thousandths of an inch, and it may serve, in case of accident, as a substitute for the larger one. The two glass vessels may be placed in the barrel itself, if it is of sufficient size. They must be placed in a reversed position, on two upright pegs, to let them drip out. As soon as the observation is made, it should be noted in pencil, not trusted to the memory; and written in the journal upon entering the house.

SNOW-GAGE.

Observation.—The *snow-gage* should be supported vertically, in an open place, between three short wooden posts, its opening being about two feet from the ground. It should be employed in the following manner:

When only a very small quantity of snow falls, or of snow alternating with rain, or of dry and fine snow, driven by the wind, it should be collected in the snow-gage, as would be done in the ombrometer. But when the snow falls in a sufficient quantity to cover the ground more than an inch deep, the vessel must be emptied, and plunged, mouth downwards, into the snow, until the rim reaches the bottom. A plate of tinned iron, or a small board, may then be passed between the ground and the mouth of the gage, and the whole reversed. In this way a cylinder of snow, of which the base is superficially one hundred inches, will be cut out, and received into the vessel. The operation may be facilitated by placing on the ground a platform of strong board or plank, two or three feet square, on which the snow is received.

The place selected for this purpose must be one where the snow has not been heaped up, or swept away by the wind, and where it presents, as near as possible, the mean depth of the layer that has fallen. In order to take only the snow which may fall in the interval between two observations, the board should be swept after each measurement, and the place designated by stakes.

Reading.—In the reading of the graduated vessels, the general surface of the liquid must be considered as the true height, and not the edges, which are always raised along the walls of the vessel by capillary attraction.

The collected snow must be melted by placing the gage, covered with a board, to prevent evaporation, in a warm room; and the quantity of water produced measured by pouring it into the glass cylinder. It need hardly be said, that if rain and snow fall the same day, no account will be taken except of what the snow-gage receives, unless the ombrometer has been observed separately after the rain, and the snow-gage after the snow. Care must be taken, in these cases, not to count twice the same quantity of fallen water.

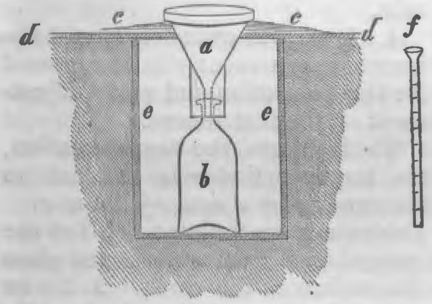
The rain-water and melted snow-water must be separately entered in the journal in the columns reserved for each.

During abundant rain-falls, it is well to measure the water more than once a day, or at least immediately after the rain; and the quantity of the rain fallen, together with the time it has lasted, is to be noted separately in the column of remarks.

When it freezes, it will be necessary to protect the receiver by filling in the interior of the barrel with straw.

[A series of observations have been made at the Smithsonian Institution with rain-gages of different sizes and different forms, the result of which, as far the observations have been carried, is to induce a preference for the smallest gages. The one which was first distributed by the Institution and the Patent Office to the observers, is represented in Fig. 10. It consists of the funnel *a*, terminated above by a cylindrical brass ring, bevelled into a sharp edge at the top, turned perfectly round in a lathe, and of precisely five inches diameter. The rain which falls within this ring is conducted into a two-quart bottle, *b*, placed below to receive it. To prevent any water which may run down on the outside of the funnel from entering the bottle, a short tube is soldered on the lower part of the former and encloses the neck of the latter. The funnel and bottle are placed in a box or small cask *e*, *e*, sunk to the level of the ground, which is covered with a board *d*, *d*, having a circular hole in its centre to receive and support the funnel. To prevent the rain-drops which may fall on this board from spattering into the mouth of the funnel, some pieces of old cloth or carpet, *c*, *c*, may be tacked upon it.

Fig. 10.

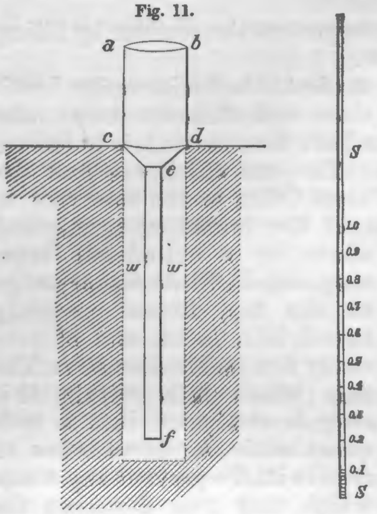


The object of placing the receiving ring so near the surface of the earth, is, to avoid eddies caused by the wind, which might disturb the uniformity of the fall of rain.

In the morning, or after a shower of rain, the bottle is taken up and its contents measured in the graduated tube *f*, and the quantity in inches and parts recorded in the register. The gage, or tube, which was first provided for this purpose, will contain, when full, only one-tenth of an inch of rain, the divisions indicating hundredths and thousandths of an inch. As this, however, is found to be too small for convenience, another gage, which will contain an inch of rain, and indicating tenths and hundredths, will be sent to observers.

Another and simpler form of the gage has since been adopted by the Institution and the Patent Office, to send by mail to distant observers. It is one of those which have been experimented on at the Institution, and is a modification of a gage which we received from Scotland, and which has been recommended by Mr. Robert Russell.

Fig. 11.



It consists of—

1. A large brass cylinder *a*, *b*, *c*, *d*, two inches in diameter, to catch the rain.

2. A smaller brass cylinder *e*, *f*, for receiving the water and reducing the diameter of the column, to allow of greater accuracy in measuring the height.

3. A whalebone scale *s*, *s*, divided by experiment ,so as to indicate tenths and hundredths of an inch of rain.

4. A wooden cylinder *w*, *w*, to be inserted permanently in the ground for the protection and ready adjustment of the instrument.

To facilitate the transportation, the larger cylinder is attached to the smaller by a screw-joint at *e*.

Directions for use.—To put up this rain-gage for use: 1. Let the wooden cylinder be sunk into the ground in a level unsheltered place until its upper end is even with the surface of the earth. 2. Screw the larger brass cylinder on the top of the brass tube and place the latter into the hole in the axis of the wooden cylinder, as shown in the figure, and the arrangement is completed.

The depth of rain is measured by means of the whalebone scale, the superficial grease of which should be removed by rubbing it with a moist cloth before its use.

Should the fall of rain be more than sufficient to fill the smaller tube, then the excess must be poured out into another vessel, and the whole measured in the small tube in portions.

Care should be taken to place the rain-gage in a level field or open space, sufficiently removed from all objects which would prevent the free access of rain, even when it is falling at the most oblique angle during a strong wind. A considerable space also around the mouth of the funnel should be kept free from plants, as weeds or long grass, and the ground so level as to prevent the formation of eddies or variations in the velocity of the wind.

To ascertain the amount of water produced from snow, a column of the depth of the fall of snow, and of the same diameter as the mouth of the funnel, should be melted, and measured as so much rain.

The simplest method of obtaining a column of snow for this purpose is to procure a tin tube, about two feet long, having one end closed, and precisely of the diameter of the mouth of the gage.

With the open end downward, press this tube perpendicularly into the snow until it reaches the ground or the top of the ice, or last preceding snow; then take a plate of tin, sufficiently large to cover it, pass it between the mouth of the tube and the ground, and invert the tube. The snow contained in the tube, when melted, may be measured as so much rain. When the snow is adhesive the use of the tin plate will not be necessary.

From measurements of this kind, repeated in several places when the depth of the snow is unequal, an average quantity may be obtained.

As a general average, it will be found that about ten inches of snow will make one of water.]

WIND-VANE.

Placing.—The *wind-vane* should be set in a place as free and open as possible, away from every obstacle, and especially from high buildings. It should exceed in elevation, by at least eight or ten feet, the neighboring objects. To facilitate observations at night, the following arrangement may be adopted:

The wind-vane is composed of a leaf of zinc about three feet in length, in the form of a butterfly's wing, exactly counter-balanced by a leaden ball. It is carried upon a cylindrical axis of pine wood, or of any other light and strong material, two inches in diameter, which, if possible, passes down through the roof into the observer's chamber, otherwise along the exterior wall of the building to a window. The axis terminates by a steel pivot turning freely on a cast-iron plate. This plate supports a dial divided into degrees, besides indicating the eight principal points of the compass. The axis carries an index placed in the same plane as the feather of the wind-vane, which enables us to read upon the dial, as well by night as by day, the direction of the wind. The whole rests on a strong wooden shelf, firmly fastened to the window by supports. Above, the rod is firmly fixed to a strong upright staff, or, better, on the roof, with strong braces, by means of a piece of wood containing friction rollers, which allow the shaft to turn freely and without effort. Similar pieces with friction rollers, placed at different distances along the wall, keep the axis vertical.

Great care must be taken to secure the perfect verticality of the shaft, and to this end it is necessary to fix it by a plumb-line in two different planes cutting each other at right angles. The index at the foot of the rod should be placed on the same side with the point of the wind-vane, and in the same plane as the feather. The pivot should turn very freely in the hole that receives it, and into which a drop of oil should be poured.

Finally, we must carefully adjust the points of the dial, which is supported with the iron plate, upon a board fastened upon a shelf by means of a strong screw. In making this adjustment by means of a compass, the magnetic variation of the locality must be taken into account; each observer should have the line of the true north traced on his window.

If the dial is exposed to the open air, it must be protected against the snow and ice, which would impede the play of the pivot and of the index. A small ring of wood placed around the pole, under one of the friction rollers, will prevent the wind-vane from being raised, and the pivot from being displaced during the most violent winds.

[As a flat vane is always in a neutral line, a more accurate and sensitive one is made by fastening two plates together at an angle of about ten degrees, forming a long wedge.

The longer the vane, the shorter the pulsations, and the steadier the action will be. For a small sized vane, it may be ten or twelve inches wide, and four feet long.]

Observation.—The observation of this instrument demands some care. In winds of considerable strength the vane is never at rest, or fixed in the same direction; it oscillates incessantly, and its oscillations increase in amplitude with certain winds, and with the violence of the wind. We must then note the mean direction between the extremes. When the wind is very feeble, perhaps it may not have sufficient force to set the vane in motion; in this case, as when the air is calm, great mistakes might be made by registering the direction marked by the index; for its position indicates, not the direction of the existing wind, but that of the last wind that had the power to set the instrument in motion. When the index is immovable, and there is no oscillation, we must give up its indications, and refer to the movement of light bodies, as that of the leaves of trees and the smoke of chimneys, to determine the direction of these feeble currents of air. During the night the direction of the wind may be easily ascertained by raing the hand in the air, with one finger wet. The least motion in the air increases evaporation, and a sensation of cold is experienced on the side of the finger turned towards the wind.

The *direction* of the wind must be noted, following the eight principal points of the compass—north, northeast, east, southeast, south, southwest, west, and northwest. For the additional observations during storms, the degrees may be indicated, in order to follow more exactly the rotation of the wind, or at least sixteen points of the compass, viz: N. NNE. NE. ENE. E. SE. ESE. SSE. S. SSW. SW. WSW. W. WNW. NW. NNW.

The lower, or surface wind, often has a different direction from that which prevails in the upper regions of the atmosphere, and this is generally the case when the wind turns, and the weather is going to change, also during storms and great atmospheric movements. The direction, then, of the lower and the higher layers of clouds must be separately noted in the several columns of the journal reserved for this purpose. If the direction is the same in the whole extent of the atmosphere, the same letters will be marked in the three columns. If the absence of clouds does not permit us to judge how the wind is above, a dash must be substituted for the letter, indicating that the observation has been made. A blank always signifies an observation omitted.

To avoid an error in the estimate of the direction of the clouds, it will be well to observe their course between two fixed points, as a window frame, the fixed lines of which will facilitate the observation. Another very convenient method is to place a small mirror horizontally, with lines traced on it indicating the points of the compass; the image of the clouds passing over these will indicate their direction.

The manner in which the wind turns, or rather the order in which the winds succeed each other in the course of the day, must be watched very carefully. It will be seen that they commonly follow in regular order; they pass from the east by the south to the west, and from the west, by the north, to the east. Nevertheless, they sometimes go back in the opposite direction, particularly during storms. A little memorandum, summing up in a few words at the end of each day this course of the wind, together with the hour's of the wind's changes, is very valuable. It may be entered in the column of remarks.

The *force* of the wind must be estimated as nearly as possible according to the following degrees:

0. A perfect calm.

The simple initial letter of the wind, for instance N. (north,) indicating its direction without any number, means a slight movement of the air hardly to be called a wind, and only just sufficient to allow an estimate of its direction.

1. A light breeze which moves the foliage, and sometimes fans the face.

2. A wind which moves the branches of the trees, somewhat retards walking, and causes more or less of a slight rustling sound in the open air.

3. A wind which causes strong boughs and entire trees to rock, makes walking against it difficult; which causes a stronger rustling sound to be heard, and which often blows in gusts, and carries light bodies up into the air.

4. A storm-wind, during which the trees are in constant motion; branches and boughs covered with foliage are broken off, and in a violent storm sometimes even entire trees are broken, or uprooted; leaves, dust, &c., are continually borne up and carried far away; during which there is an uninterrupted loud rustling sound, with strong gusts; walking windward is extremely difficult, and now and then chimneys, fences, &c., are thrown down, windows broken in, &c.

These degrees correspond nearly to the following numbers of Beaufort's scale, which is generally used among seamen:

1. the same as 1. Light breeze,
2. " " " 4. Moderate breeze,
3. " " " 8. A fresh gale,
4. " " " 11. A storm-wind,

of Beaufort's scale.

[The force of the wind is now estimated and registered according to the direction on the blank forms.]

SKY.

The blue color of the sky has an intimate connexion with the hygrometrical state and the electrical tension of the air; it may be noted by the expressions, *dark, light*, and *greyish*.

Haze and dry mist.—The transparency of the air is often disturbed by a kind of vapor, which gives a whitish tint to the sky and dims the rays of the sun. This phenomenon, known in Europe under different names, appears frequently after long droughts; in this country it seems to characterize the Indian summer. In Europe, and elsewhere, an intense dry mist, which is, probably, a different phenomenon, sometimes follows great earthquakes or volcanic eruptions. The observer will carefully enter phenomena of this kind, and the circumstances under which they appear or disappear. If he has an opportunity, as in a high station, he should endeavor to ascertain if there is an upper limit, and what is the thickness of the layer of haze or dry mist. Observations made in the Alps prove that the atmosphere is often entirely free from it at a height of two thousand feet, when it is very intense in the plain. Does a thunder-storm or rain always cause it to disappear? Do the prairie fires have any relation with kindred phenomena? Does it appear more frequently in certain seasons than in others?

HYDRO-METEOROLOGICAL PHENOMENA.

DEW.

The *dews*, especially when they are abundant, and

The *white frosts*, or frozen dew, particularly the first and last of the year, and their intensity, must be entered.

FOG.

Fog.—The moment must be noted when it forms and when it dissipates, as *falling* fog, *rising* fog; its density, as *dense* fog, *slight* fog.

Mists hanging over forests, moors, meadows, rivers, or the like.

Notice must be carefully taken of the time of their appearance or disappearance; these are the most important facts in regard to them.

These fogs must not be confounded with the dry fog, which belongs to another class of phenomena, which have been spoken of above.

CLOUDS.

For noting these the observer must go out to a place entirely free, in case his residence has too confined a horizon.

The *cloudiness* or the quantity of clouds, after some practice, can be easily estimated, in accordance with the following scale. Thus, we understand by—

0. A clear sky, entirely free from clouds;
10. The whole sky covered with clouds, or a dense fog, or rain; and by 1, 2, 3, 4, 5, 6, 7, 8, 9, the different degrees of cloudiness which lie between these:
1. Denotes, for instance, nine times as much blue sky as clouds;
5. An equal amount of clouds and blue sky;
9. Nine times more clouds than blue sky.

If, on account of the locality, it is impossible for the observer to estimate the quantity of clouds in this way, he can make use of the following expressions, which will mark at the same time the medium character of the aspect of the sky during each day:

Wcl. Wholly clear; a sky entirely free from clouds.

Cl. Clear; when at least two-thirds of the sky is unclouded.

M.	Medium; the clouded part of the sky nearly equal to the blue.
C.	Cloudy; a larger part cloudy than clear.
Ov.	Overcast; the clouds rarely broken.
Cov.	Covered sky; without any visible spot of blue.

The form of the clouds will be indicated by the terminology of Howard.

According to this, they are distinguished by their external forms into three kinds: the *cirrus, cumulus*, and the *stratus*, to which belong four transition forms, the *cirro-cumulus*, the *cirro-stratus*, the *cumulo-stratus*, and the *nimbus*. The most remarkable of these forms may be characterized in the following manner:

The *cirrus*, or cat-tail of the sailors, is composed of loose filaments, the whole of which sometimes resembles a pencil, sometimes curly hair, sometimes a fine net, or a spider's web.

The *cumulus*, or summer cloud, the cotton-bale of the sailors, often shows itself under the form of a hemisphere resting on a horizontal base. Sometimes these half spheres are piled upon one another, forming those large accumulated clouds in the horizon which resemble at a distance, mountains covered with snow.

The *stratus* is a horizontal band, which is formed at sunset and disappears at sunrise.

The *cirro-cumulus* are those small rounded clouds, which are often called fleecy; when the sky is covered with clouds of that kind it is said to be mottled.

The *cirro-stratus* is composed of small bands, formed of closer filaments than those of the cirrus, for the rays of the sun often find it difficult to penetrate them. These clouds form horizontal beds, which, at the zenith, seem composed of a great number of loose clouds, while at the horizon a long and very narrow band is seen.

The *cumulo-stratus* is a mass of heaped up and dense cumuli. At the horizon they often assume a dark or bluish tint, and pass into the condition of *nimbi*, or rain clouds.

The *nimbus* is distinguished by its uniform grey tint, its fringe and indistinct edges; the clouds composing it are so blended that it is impossible to distinguish them.

But besides these principal forms, there are several intermediate, to which it is difficult to assign a name. They must be referred to the form which they most resemble.

They may be entered in the journal by means of the following abbreviations:

St.	i. e.	Stratus.
Cu.	"	Cumulus.
Cir.	"	Cirrus.
Cir. st.	"	Cirro-stratus.
Cu. st.	"	Cumulo-stratus.
Cir. cu.	"	Cirro-cumulus.
Nim.	"	Nimbus.

If several of these forms are visible, the most frequent should be underlined, and the others should follow the order of their frequency. The distribution of the clouds in the sky should be noted, whether they are dispersed or accumulated in a special region of the heavens, in the horizon, at the zenith, &c.

RAIN.

It is necessary to note as accurately as possible the hour at which the rain begins and ends; if it is a continued rain, or at intervals and in showers; if it is general or only partial, preceded, followed, or accompanied by fogs; the size of the drops and the force of the rain should be also noted. For these different cases, the following designations may be adopted:

Rainy, when the fall of some drops and the appearance of the weather is such as to indicate the approach of rain.

Continued rain.

Interrupted rain.

Shower, which lasts not more than a quarter of an hour.

General rain, which prevails over the whole extent of the horizon.

Partial rain, which falls from the clouds that pass over only a small extent of country.

The force of the rain may be indicated by the following gradations:

Drizzling rain, which falls in very small drops, almost like those of mist.

Slight or fine rain.

Moderate rain.

Heavy rain.

Violent rain, heavy and strong pelting rain.

The size of the drops seems to depend chiefly upon the height of the clouds, and consequently upon the seasons and the circumstances of the temperature.

The snow.—The period of the first and last snow, the size of the flakes, their forms.

Sleet, which consists in small balls of snow, white and opaque, commonly without a crust of ice, like the opaque nucleus found within hail-stones, falling more frequently in spring and in autumn.

Frozen rain drops should be distinguished from the preceding forms; they make little balls of transparent ice.

Hail.—Indicate the size and form of the hail-stones, the extent and course of the phenomenon.

THUNDER-STORMS.

The time of beginning and ending of the storm must be indicated as exactly as possible; the point of the horizon whence it rises, the direction of the clouds, of the wind and its variations, and, if possible, the quantity of rain before and during the storm; of hail, &c., which falls, note if it passes over the place of the observation, or at a distance; if it is accompanied, or not, with strong electrical detonations and numerous lightnings. It will be well to ascertain the state of the meteorological instruments during the storm, especially of the barometer and the thermometer.

In the journal, the occurrence of a storm will be indicated in the column of remarks merely by the letters *Th St*, with the hour when it took place. If special observations have been made with the instruments, they wil be entered on the opposite side of the sheet in the columns reserved for additional observations, taking care to note the day and the hour. If the observations require a more detailed description, it may be made on a separate sheet.

TORNADOES AND LAND-SPOUTS.

These whirlwinds, or violent and circumscribed storms, give rise to very complex phenomena, which are difficult to observe. All the meteorological circumstances, however, should be minutely noted; among others the following:

The course of the barometer, which almost always sinks much and rapidly; that of the thermometer, which usually indicates an elevation of temperature; the region of the heavens in which the thunderstorm frequently accompanying them is formed; the form and color of the clouds; the direction and intensity of the wind; the frequency, the size, and the form of the lightnings; finally, the apparent shape of the land-spout, its variations, its course, and its effects upon the trees and upon the ground.*

ADDITIONAL OBSERVATIONS DURING STORMS.

Everybody knows the importance of a knowledge of the laws of those great movements of the atmosphere which embrace almost the whole extent of the continent. It is only in following them, step by step; by observing their different phases at different places, and by combining the facts obtained, that the meteorologist can be enabled to discover the laws which preside over these great phenomena. For this, the three regular observations a day are insufficient; it is then earnestly recommended to observers, who desire to contribute effectually to the solution of this great problem, not to content themselves with the prescribed number, but to add as many more as possible during the continuance of remarkable storms; noting not only the state of the instruments from hour to hour, if possible, but following with attention all the meteorological changes. These observations must be entered on the reverse of the sheet, under the head of *additional observations*, which is particularly reserved for this purpose.

The principal points to which attention should be directed are the following:

The *barometer* announces by a considerable fall the approach of a storm. Then it begins to rise during its continuance, and only resumes its nominal equilibrium after its close. Remark especially the following points:

Was the storm preceded by a noticeable or sudden rise previous to the fall.

Note the state of the barometer, and the time when the fall becomes more rapid;

Its state, and the time, when it is lowest and when the rise begins;

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* For more detailed instructions upon the observations of land-spouts, see the Annuaire Météorol. de France, 1849, p. 225.

The highest point which it reaches during, or immediately after the storm.

If alternations of rising and falling take place, the fact should be mentioned and the time noted.

The thermometer.—The fluctuations of the thermometer in the same time as those of the barometer should also be noted, and their connection with the changes of the wind be observed.

The wind.—It is of the greatest importance to observe the course of the winds through the entire height of the atmosphere during the whole continuance of the storm, by means of the wind-vane and of the clouds in the different layers of the atmosphere.

The hour when the wind begins, and the direction whence it comes;

The moment of its greatest violence;

The instant it changes its direction, and when it takes the direction it keeps to the end of the storm.

It should be stated if the wind blows in a continuous manner or in squalls, and what is its force.

If there should be one or more moments of calm, the hour and duration will be indicated.

Great care must be taken at each observation to note also the direction of the different layers of clouds, which will very often be found different from that of the wind below, for the whole duration of the storm.

The clouds.—Are there certain forms of clouds which announce the approach of a storm? It is necessary, in this connection, to watch the formation of the cirrus, the cirro-cumulus, cirro-stratus, their arrangement in parallel lines, their course, and their directions. Note the quarter of the sky first covered with clouds; the moment when it is entirely covered; if there are later clear spots or not; the moment when the sky clears off.

The rain.—Note the hour at which the rain or the snow begins and ends; measure the quantity fallen while the storm lasts.

ACCIDENTAL METEORIC PHENOMENA.

These will be entered in the tables, in the place reserved for this purpose on the opposite side of the sheet. If the space is not sufficient for the description to be given, the phenomenon should be simply noted, and reference made to a separate account for details. Thus:

The solar and lunar haloes—that is, the colored circles sometimes observed round the sun and moon. Distinguish the small ones, the ring of which measures only a few degrees, from the large or real haloes, the ring of which has a diameter of about forty-four degrees. It must be stated whether they are connected with other circles, as is sometimes the case. Care must be taken not to mistake a part of a grand halo for a rainbow. Note whether these appearances are, or are not, ordinarily followed by rain.

The Parhelia and Paraselenes, (mock-suns and moons.)—Describe exactly their forms and the state of the heavens at the moment of their appearance.

Rainbows, simple or double.

An extraordinary *redness* of the sky, either in the morning or evening; the particular color of the sun and of the moon at their rising, especially in fair days.

Heat lightnings without thunder, and sometimes without clouds; indicate their direction and the aspect of the clouds in their neighborhood.

The *Aurora Borealis*, or northern light, for the observation of which the special instructions published by the Smithsonian Institution must be followed.

Shooting-stars.—The observer must be particularly attentive to their frequency, during the periods near the 10th and 11th of August, and the 10th and 15th November, in which it is supposed that they are more numerous than at any other time. He will designate the quarter of the heavens from which they seem to issue, and their direction.

Fireballs.—Describe their aspect, their size, their course in the heavens, and note the exact hour of their appearance.

All the other luminous phenomena, which present any extraordinary appearance, should be noted down.

These descriptions should be made in simple and well-defined terms. The observer will take great care to enter scrupulously *what he sees*, without drawing any conclusion, or attempting any explanation of the phenomenon. He ought to reflect that, in order to make a good observation, he must keep his mind in a state of perfect disinterestedness in respect of any preconceived theory, and to consider the phenomenon before him as being one of the data for the foundation of the science, and that the knowledge of the truth will depend upon the fidelity of his observation.

TIME OF OBSERVATIONS.

The time of observations will be the mean time at each station. The observations will be made three times daily, viz:

At 6 o'clock, a. m.
2 " p. m.
10 " p. m.

The mean of these three hours will be very nearly the true mean, as it would be obtained by observation made every hour of the day and night. They are at intervals of eight hours from each other, and are the least inconvenient possible for the daily occupations of life; they must be preferred to any other series of three equidistant hours.

[For convenience of observation the hours which have been adopted by the Institution are 7, 2, and 9.]

The ombrometer will be observed only once a day, unless very abundant rains should make a second measurement necessary. The best time will be 2 o'clock p. m., the observation being made daily; if another hour is selected, it should, when once fixed, remain the same.

The maxima and minima thermometers will be read once a day, always at the same hour. The most suitable hour will be 10 o'clock in the evening.

If an observer desires to examine the daily oscillations of the barometer he will also observe at 10 a. m. and 4 p. m., which give the daily maximum and minimum. It will be well to note also, at the same time, the state of the hygrometer.

If he desires to complete the data upon the diurnal course of the temperature, he will add observations of the thermometer at 10 a. m., and 6 p. m. In all cases it is desirable that, if an observer has leisure to increase the number of the hours of observations, he should fix them at equal intervals between the principal hours indicated above.

Besides these observations at regular hours, additional observations ought to be made during remarkable storms, as has been remarked above.

It is very important that the observations should be made at the exact hour, fixed by a well regulated watch. All the instruments should be read rapidly, so that the observations may be as simultaneous as possible.

The order in which they are to be observed will be as follows:

A few minutes before the hour, observe the thermometer before opening the window; then wet the psychrometer. While it is taking the temperature of evaporation, note the height of the barometer, observe the wind, the course of the clouds, their quantity, the aspect of the sky, &c.; then read the temperature of the psychrometer.

The observations must be recorded for each instrument at the moment when they are made, without trusting anything to the memory. A strict rule should be laid down for one's self, to note exactly the indications of the instruments, without subjecting them mentally to any corrections or any reductions; these should not be applied until all the elements are at hand.

If the observer has been unavoidably hindered from making the observations at the exact hour, he will note in the column of hours the number of minutes of the delay. If he is obliged to procure a substitute, he must choose one accustomed to this kind of observation; but before entering his records, he will carefully examine them. To distinguish the observations made by his substitute, he will enter them in red ink.

As it is of the greatest importance that the series of observations should not be interrupted, and that there should be no omissions, each observer will do well to instruct beforehand one or more substitutes, who may be able upon occasion to take his place. If, in spite of these precautions, the observation has necessarily been omitted, its place will be left blank in the journal. In this case the observer must never fill up these blanks with calculations, according to his judgment; he should consider the conscientious observance of this rule indispensable to truth and good faith. He should remember, besides, that if he acts differently, he not only lessens the value of these results, but brings into doubt and disfavor the fidelity of his other observations, and takes from them what constitutes their greatest value for science—*confidence.*

THE REGISTER.

In the register the first page is devoted to regular observations; the second to additional observations, to periodical or extraordinary phenomena, and to monthly recapitulations. The headings of the columns indicate clearly the use of each.

For each instrument the columns follow each other in the order in which the observations are to be made, and one column is reserved to enter the observation *just as it is made*, and before any correction or reduction. As each sheet is to be regarded as an independent document, it should carry with it all that is necessary to correct the observations therein contained, and to render them authentic. Thus, the date of the year, the month, the precise locality, the latitude and longitude, the elevation of the instruments from the ground and above the sea, the nature and condition of the instruments which have been employed, and the amount of their corrections; finally, the signature of the observer, should be repeated on every leaf. It will be sufficient, for this, to fill the blank spaces left after the different printed titles in the blank forms. The observer should the less neglect this important duty, as it is an affair of only a few strokes of the pen each month, without which his labor would run the hazard of losing its value.

Thermometer.—In the thermometrical observations the quantities above zero will be *always* written without a sign; the negative quantities will be all *individually* marked with the sign *minus*, (—,) whether they follow each other or are isolated. In the first column, entitled *daily mean*, will be inscribed the mean of the three observations of the day, *i. e.* their sum divided by 3, admitting two decimals. In the second column of the daily mean will be inscribed the mean of the maximum and the minimum, given by the thermometrograph, or self-registering thermometers.

Barometer.—The degree of the attached thermometer and the observed height of the barometer will be inscribed in the first two colums. This height will be reduced to freezing-point, or 32° Fahrenheit, or zero Centigrade, by means of the annexed tables, and the whole correction of the instrument, indicated on the back of the sheet, will be applied to it. It will then be inscribed in the third column, entitled *corrected height* at freezing-point. These corrected heights, and never any others, must be employed to form the mean, which will be inscribed in the fourth column.

Psychrometer.—In the first two columns will be entered the indications of the dry and wet thermometer, after having applied to each of them the correction of the instruments, if there be any; and in the third column the difference of the two numbers. By means of the psychrometrical tables will be found the *force of the vapor* and the degree of *relative moisture*, each of which has its column, as well as the daily means of each of these elements.

We have indicated above the manner of noting the *direction* of the winds.

As to the *force* of the *surface* wind, which alone can be estimated with some degree of precision, it will be expressed by adding to the letter which designates the direction, the figure indicating its force: *e. g.*, N, without a figure, signifies a slight air, hardly perceptible, coming from the north; N_1, a slight breeze; N_3, a strong wind, &c. The other two columns will have only letters, or a dash (—) if the observation has not been possible.

The quantity of clouds, or the *cloudiness* estimated from zero, or a perfectly clear sky, to 10, sky entirely overcast, has a separate column.

It is the same with *rain* and *melted snow*, which will be separately entered. A third column is reserved for the total quantity of both. The thickness of the layer of fallen snow may be indicated in inches and tenths.

As to the broad column reserved for the *aspect of the sky, and remarks,* although it is desirable, considering the small space the form of the table allows, to employ abbreviations to express the state of the sky and the different meteorological phenomena; nevertheless, we must limit ourselves to a small number, chosen from among the expressions which most frequently occur, such as those found at the bottom of the blank forms. If abbreviations are too much multiplied, we lose in clearness and certainty what we gain in conciseness. A meteorological journal should not resemble a page of algebra, where a badly formed letter or a misplaced sign renders the expression unintelligible.

For the additional observations the same rule should be followed.

In the space reserved for *periodical and extraordinary phenomena,* the phenomena will be inscribed with their dates and the hour of their appearance.

Every change of position, or in the condition of the instruments, should be carefully entered under the head of *Condition of the instruments,* with the precise date at which it took place. If there has been none, *instruments all in order* will be entered. By the side of the indication of the correction of the instruments will be placed, *correction applied* or *correction not applied,* according as the observations contained in the sheet shall have been corrected or not. The finished sheet will be signed by the observer.

The *reductions*, the *corrections*, and the *calculations of means*, must be made day by day and at the end of each month with the greatest punctuality. The necessary tables will be placed at hand by the side of the journal, and each observation reduced, and the correction, if any, applied immediately.

This is not only the least troublesome method, but the only one which permits the observer to control the observations and the reductions, and to discover the accidental errors of the pen and of the reading in the record.

The observer cannot be too thoroughly convinced that a meteorological journal which contains only rough observations, is only half made; in this condition it is wholly unfit to serve any scientific purpose. The observations cannot be compared rigorously with each other, nor with those of other stations. The only means for the observer to give its true value to his labor, is to make the corrections, the reductions, and the calculations of the means himself. It is for want of having thus been elaborated that voluminous collections of observations, the fruits of long years of toil, remain useless and forgotten in the dust of libraries, because the meteorologist finds it impossible to make use of them without first undertaking those calculations, the amount of which absolutely transcends the powers of an individual, and would discourage the most ardent zeal, while they would have cost the observer only an instant each day, if he had made them at the time of the observations.

The calculations desirable are as follows:

1. Each barometrical observation must be reduced immediately to the temperature of zero Centigrade, or 32° Fahrenheit, by means of the tables, and the total correction of the barometer, if there is any, will be applied.

2. The diurnal means of the several instruments, resulting from the sum of the three observations made at these different hours, divided by three, must be entered each day in the respective columns, after the observation of 10 p. m., [9 p. m.] It is needless to say that these means should be drawn solely from observations reduced and corrected.

3. The monthly means for each hour separately—that is, the monthly mean of the observations of 6 a. m., [7 a. m.,] and that of 2 p. m., and of the observations of 10 p. m., [9 p. m.]

4. The monthly means drawn from the means of each day; the monthly extremes of the instruments; the monthly amount of the rain, hail, or snow; the mean cloudiness of the sky; the prevailing wind, &c.

5. The annual means and amounts, and the respective extremes for the civil year.

It will be interesting to calculate also, if the observer is so disposed, the mean of the seasons of the meteorological year, which begins December 1, to November 30, of the following civil year:

The meteorological seasons are, then:

Winter—December, January, February.
Spring—March, April, May.
Summer—June, July, August.
Autumn—September, October, November.

In calculating all these different results, we should take, in order to be very exact, the means of the sums of all the observations during the period of time in question, by reason of the inequality of the length of the months.

The sums which form the basis of all these means should be inscribed in the tables in the place reserved for them.

The preceding calculations, after a little practice, will not appear difficult, and may be quickly performed; but it can hardly be too often urged upon the observer to make them without delay; otherwise, this task, which is slight if accomplished daily, would become very heavy, if left to accumulate for several months. It is only by making the correction himself that the observer can institute his own comparisons, and really study the course of the meteorological phenomena. His interest will increase still more with the feeling that he is coöperating in a great work, which concerns at once his whole country and the science of the world, and the success of which depends upon the accuracy, fidelity, and devotion of all who take part in it.

A copy of the observations of each month must be forwarded for publication during the first week of the following month. It should be carefully collated by two persons, one of whom reads the figures aloud. Each observer will receive for this purpose a double series of blank forms, one of which will be retained by him.

Many of the phenomena connected with the state of the atmosphere are of great interest for comparative climatology, especially in a practical point of view. The periodical phenomena of vegetation and of the animal kingdom, such as the epoch of the appearance and the fall of the leaves, of the flowering and ripening of the more generally cultivated fruits; the seed time and harvest of plants; the coming and going of migratory birds; the first cry of the frogs, the appearance of the first insects, &c.; the moment of the closing of rivers, lakes, and canals by ice, and of their opening; the temperature of springs at different periods of the year; the temperature in the sun compared to that observed in the shade; that of the surface, and that below the surface of the ground. All observations of this kind are valuable.

The observer will find it very instructive to project curves which indicate the diurnal monthly or annual variations of temperatures, of atmospheric pressure, of moisture, &c., as well as thermometrical, barometrical compasses, or circles, &c.

These graphic representations are of the greatest utility for the comparisons, speaking to the eye more clearly than simple figures.

Besides the above directions for keeping an ordinary Meteorological Journal, more special instructions for the study of peculiar meteorological phenomena are prepared by the Smithsonian Institution; as on

Thunder-storms, Tornadoes, and Water-spouts, Aurora Borealis, Parhelia, Parasalenes, Haloes, Rainbows, Temperature of the soil, Periodical phenomena of the vegetable and animal kingdoms, Graphic representations of meteorological phenomena, &c. If any observer should feel inclined to devote himself to the study of any one of these physical problems, he may receive, on application, the special instructions relating to the point which he wishes to investigate.

[The directions given in the preceding article are not intended to supersede those printed on the sheet of blank forms issued jointly by this Institution and the Patent Office, but to impart additional instruction, particularly to those who are furnished with a full set of instruments and desire to attain as much precision as possible.]

METEOROLOGY.

CIRCULAR RELATIVE TO EARTHQUAKES.

SIR: The Smithsonian Institution is desirous of collecting information in reference to all phenomena having a bearing on the physical geography of this continent; and, in behalf of the Board of Regents, it is respectfully requested that you will furnish us with any information which you may possess, or be able to obtain, in regard to the earthquake which lately occurred in your neighborhood.

It will be interesting to determine the geographical limits of the disturbance, and to ascertain whether it was confined to any particular geological formation. If the direction of the shock was observed at a few places, the centre of commotion could be determined; and if the time were accurately known at different points, the velocity of the earth-wave could be calculated. Hence, an answer is requested to the following questions, viz:

1. Was the agitation felt by yourself, or by any other person in your vicinity?
2. What was the approximate time of the occurrence?
3. What was the number, and duration, of the shocks?
4. What was the direction of the motion?
5. What was the character of the disturbance? was it vertical, horizontal, or oblique? was it an actual oscillation? an upheaval and depression, or a mere tremor?
6. Was there any noise heard? and if so, what was its character?
7. Was the place of observation on soft ground, or on a hard foundation near the underlying rocks of the district?
8. Were any facts observed having apparently an immediate or remote bearing on this phenomenon?
9. What was the intensity of the force in reference to producing motion in bodies and cracks in walls?

NOTE.—Please reply to the *first* question, if to no other—for an answer to it is necessary, in order to determine the limits of the commotion.

The direction of the impulse may have been ascertained by observing the direction in which molasses, or any viscid liquid, was thrown up against the side of a bowl. The remains of the liquid on the side of a vessel would indicate the direction some time after the shock occurred.

Very respectfully, your obedient servant,
JOSEPH HENRY,
Secretary Smithsonian Institution.

METEOROLOGY.

INSTRUCTIONS FOR OBSERVATIONS OF THE AURORA.*

GENERAL REMARKS.

Though the aurora borealis has received attention during a considerable portion of the last two centuries, definite information is still wanting on several points which may serve as the basis of a sound induction as to its cause. These relate particularly to the actual frequency of the appearance of the meteor; its comparative frequency in the different months of the year and different hours of the day; the connexion of the appearance of the meteor with other atmospherical phenomena; the elevation and extent of visibility of the arch; and whether the same or different phases are presented to individuals at different stations at the same moment of time; finally, the precise influence of the arches, streams, &c., on the magnetic condition of the earth; and whether any unusual electrical effects can be observed during the appearance of the meteor.

Auroral phenomena may be divided into the following classes:

1. A faint light in the north, without definite form or boundary.
2. A diffused light, defined by an arch below.
3. Floating patches of luminous haze—sometimes striated.
4. One or more arches, resembling the rainbow, of uniform white color, retaining the same apparent position for a considerable time, and varying in luminosity.
5. A dark segment, appearing under the arch.
6. Beams, rays, streamers, waves, transverse and serpentine bands, interrupted or checkered arches, frequently tinged with color, and showing rapid changes in form, place, and color.
7. Auroral corona, or a union of beams south of the zenith.
8. Dark clouds accompanying the diffuse light.
9. Sudden appearance of haze over the whole face of the sky.

The following may serve as a scale of brightness:

1. Faint. 2. Moderate. 3. Bright. 4. Very bright.

GENERAL DIRECTIONS.

1. Make a regular practice of looking for auroras every clear evening, from 8 to 10 o'clock, or later. Record the result, whether there be an aurora or not.

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* These instructions are principally adopted from those used in the Observatory at Toronto, Canada.

2. Note the time of observation, and compare the watch used with a good clock, as soon after as is convenient.

3. Make a return of the latitude and longitude of the station.

4. Note the class to which the auroral phenomenon belongs.

5. If it be an arch, note the time when the convex side reaches any remarkable stars, when it passes the zenith, disappears, &c.

6. If the arch be stationary for a time, mark its position among the stars on the accompanying map, so that its altitude may be determined.

7. If it be a streamer or beam, mark its position on the map, and the time of its beginning and ending.

8. If motion be observed in the beams, note the direction, whether vertically or horizontally, to the east or west.

9. Note the time of the formation of a corona, and its position among the stars.

10. Note the time of the appearance of any black clouds in the north near the aurora; also, if the sky be suddenly overcast with a mist at any time during the auroral display.

11. Give the direction and force of the wind at the time.

12. Note if any electrical effects are observed.

13. Note the effect upon a delicately suspended magnetic needle.

USE OF THE MAP.*

1. To define the place and the extent of the aurora, the observer should familiarize himself with the relative position of the stars in the northern sky, by frequent inspection of the accompanying map, or a celestial globe.

2. Let the observer place the map before him, with the constellations in the positions in which they actually appear at the time of the observation. This may be done by holding up a plumb-line between the eye and the pole star, noticing the stars which it cuts; then a light pencil drawn through these stars and the pole on the map will be the centre of the heavens, or place of the meridian at the moment.

3. Mark carefully the place among the stars of the arch of the aurora, and show its width by parallel curved lines. Make a note of the time.

4. Draw a light curved line, following, as nearly as can be judged, the outline of the arch down to the horizon, on each side.

5. If the arch changes its position, mark its new places at intervals, noting the time of each observation.

6. Letter each position A, B, C, &c., and note the time and other particulars on the back or margin of the map, or in the register.

7. Beams or corruscations, or streamers of white or colored light, may be marked by lines at right angles to the above, with arrow heads pointing towards the place among the stars to which they tend, or where they would meet, if prolonged.

8. To aid in the estimation of angular distances the spaces between certain conspicuous stars have been marked on the map, which will furnish a scale to assist the eye, when actual measurement may be impracticable.

9. The course of brilliant meteors, when they fall within the por-

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* Copies of the map will be furnished by the Institution.

tion of the heavens included on the map, may be marked by a line, the length of which will show the path of the meteor; the course should be indicated by an arrow, and the time recorded.

MAGNETIC APPARATUS.

Few observers will probably be furnished with a regular set of magnetical instruments. A temporary apparatus may, however, be fitted up at comparatively little expense and trouble. For this purpose a steel plate, such as was used a few years since for ladies' busks, may be magnetized and suspended edgewise in the vertical plane, by a few fibres of untwisted silk, in a box to prevent agitation by the air, furnished with a glass window on one side, through which observations may be made. To render the motions perceptible, a small mirror should be cemented on the side of the magnet opposite the window. In front of this mirror, and at the distance of ten or fifteen feet, an ordinary spy-glass is fastened to a block, and under the glass, to the same block, a graduated scale, with arbitrary divisions marked upon it, is attached. The arrangement is such that the divisions of the scale may be seen through the telescope, reflected from the mirror, and consequently the slightest motion of the needle, and of the mirror cemented to it, gives a highly magnified apparent motion to the scale. The mirror may be formed of a flat piece of steel, highly polished by means of calcined magnesia; or, in default of a mirror of this kind, a piece of plate looking-glass may be employed, provided one can be procured sufficiently true. The suspension threads should be five or six feet long. The instrument should not be placed very near large masses of iron, and care should be taken not to change the position of any articles of iron which are within the distance of fifteen or twenty feet, otherwise a change in the position of the needle will be produced. For a similar reason the box should be constructed without iron nails. The above described instrument will indicate changes in the direction of the magnetic meridian. A similar instrument, deflected at right angles to the magnetic meridian by the torsion of two suspended threads, will furnish an apparatus for indicating changes of horizontal magnetic force.

ELECTRICAL APPARATUS.

To ascertain whether any change takes place in the electrical state of the atmosphere during the appearance of an aurora, the end of a long insulated wire, suspended from two high masts or two chimneys by means of silk threads, may be placed in connexion with a delicate gold leaf electrometer. Any change in the electrical state of the atmosphere, simultaneous with the aurora, will be indicated by the divergence of the leaves. Two slips of gold-leaf attached by a little paste to the lower end of a thick wire, passing through a cork in a four-ounce vial, will answer for this purpose. The arrangement of the leaves will be best made by a bookbinder, who is expert in the management of gold-leaf.

The map when filled, together with any written observations, may be returned to the Smithsonian Institution, endorsed Meteorology.

[A continuous series of photographic registers of the motion of the magnetic needle is now kept up at the joint expense of the Coast Survey and this Institution, which will serve for comparison with any observations which may be made on the aurora.]

Prof. Olmsted, in a recent paper published by the Smithsonian Institution, classifies different auroras as follows:

"CLASS I. This is characterized by the presence of at least *three* out of four of the most magnificent varieties of form, namely, arches, streamers, corona, and waves. The distinct formation of the corona is the most important characteristic of this class; yet, were the corona distinctly formed, without auroral arches or waves, or crimson vapor, it could not be considered as an aurora of the first class.

"CLASS II. The combination of *two* or more of the leading characteristics of the first class, but wanting in others, would serve to mark class the second. Thus the exhibition of arches and streamers, both of superior brilliancy, with a corona, while the waves and crimson columns were wanting, or of streamers with a corona, or of arches with a corona, without streamers or columns, (if such a case ever occurs,) we should designate as an aurora of the second class.

"CLASS III. The presence of only *one* of the more rare characteristics, either streamers or an arch, or irregular coruscations, but without the formation of a corona, and with but a moderate degree of intensity, would denote an aurora of the third class.

"CLASS IV. In this class we place the most ordinary forms of the aurora, as a mere northern twilight, or a few streamers, with none of the characteristics that mark the grander exhibitions of the phenomenon."

The same author remarks:

"On the evening of the 27th of August, 1827, after a long absence of any striking exhibition of the aurora borealis, there commenced a series of these meteors which increased in frequency and magnificence for the ten following years, arrived at a maximum during the years 1835, 1836, and 1837, and, after that period, regularly declined in number and intensity until November, 1848, when the series appeared to come to a close. The recurrence, however, of three very remarkable exhibitions of the meteor in September, 1851, and of another of the first class as late as February 19th, 1852, indicates that the close was not so abrupt as was at first supposed; but still there was a very marked decline in the number of great auroras after 1848, and there has been scarcely one of the higher class since 1853.

"A review of the history of the foregoing series of auroras appears to warrant the conclusion that it constituted a definite period, which I have ventured to call the "Secular Period," having a duration of little more than twenty years; increasing in intensity pretty regularly for the first ten years, arriving at its maximum about the middle of this period, and as regularly declining during the latter half of the same period."

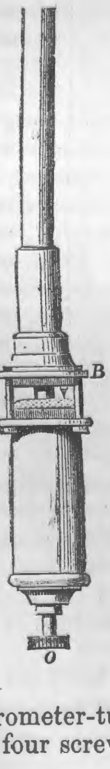
If this view be correct, it would appear that but few brilliant displays of the aurora may be expected for a number of years to come.

METEOROLOGY.

GREEN'S STANDARD BAROMETER.

The following is an account of Green's improved standard barometer, adopted by the Smithsonian Institution, for observers of the first class.

The barometer consists of a brass tube, (Fig. 1) terminating at top in a ring A, for suspension, and at bottom in a flange B, to which the several parts forming the cistern are attached.



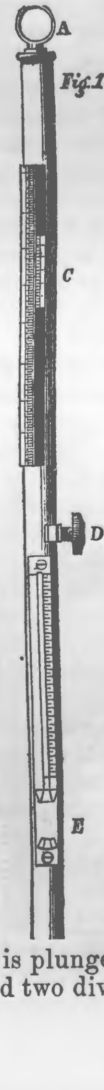


Fig. 1

The upper part of this tube is cut through so as to expose the glass tube and mercurial column within, seen in Fig. 5. Attached at one side of this opening is a scale, graduated in inches and parts; and inside this slides a short tube *c*, connected to a rack-work arrangement, moved by a milled head D: this sliding-tube carries a vernier in contact with the scale, which reads off to $\frac{1}{500}$ (.002) of an inch.

In the middle of the brass tube is fixed the thermometer E, the bulb of which being externally covered, but inwardly open, and nearly in contact with the glass tube, indicates the temperature of the mercury in the barometer tube, not that of the external air. This central position of the thermometer is selected that the mean temperature of the whole column may be obtained; a matter of importance, as the temperature of the barometric column must be taken into account in every scientific application of its observed height.

The cistern (Fig. 2) is made up of a glass cylinder F, which allows the surface of the mercury *q* to be seen, a top-plate G, through the neck of which the barometer-tube *t* passes, and to which it is fastened by a piece of kid leather, making a strong but flexible joint. To this plate, also, is attached a small ivory point *h*, the extremity of which marks the commencement or zero of the scale above. The lower part, containing the mercury, in which the end of the barometer-tube *t* is plunged, is formed of two parts *i j*, held together by four screws and two divided rings *l m*, in the manner shown in the

Fig. 5

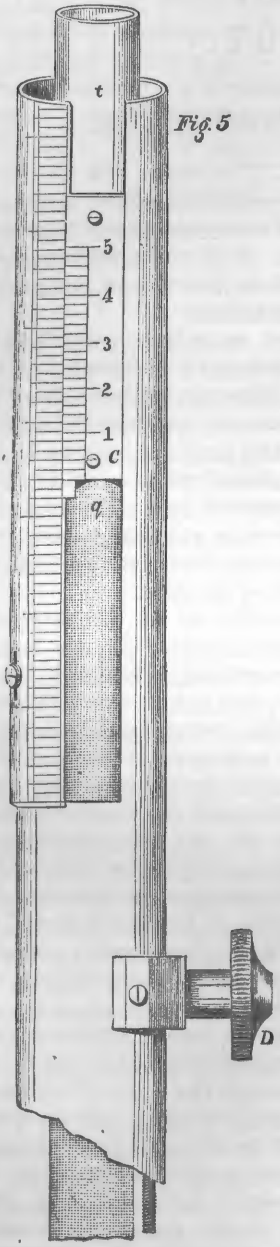


Fig. 2

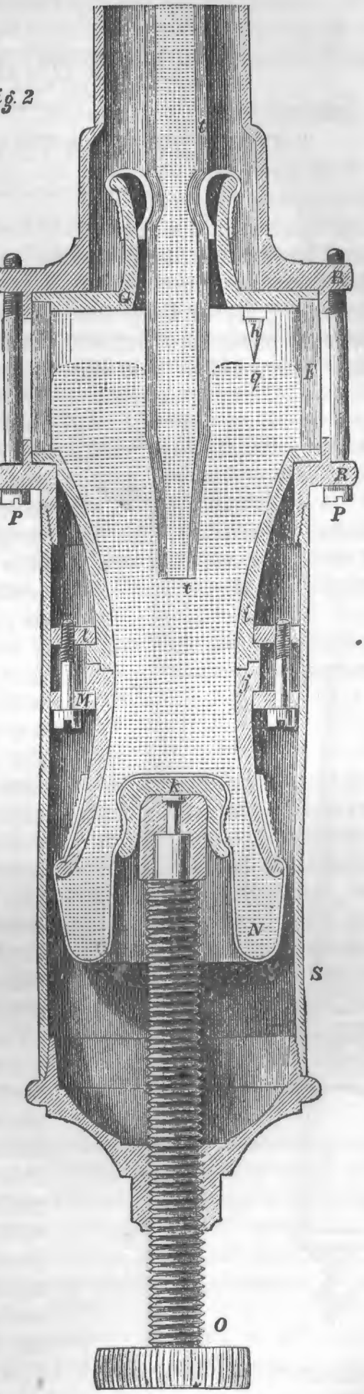
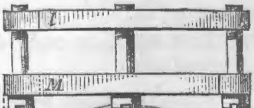


Fig.4



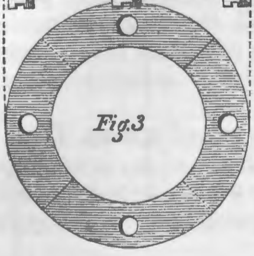


Fig.3

figures 2, 3, and 4. To the lower piece *j* is fastened the flexible bag *n*, made of kid leather, furnished in the middle with a socket *k*, which rests on the end of the adjusting-screw O. These parts, with the glass cylinder F, are clamped to the flange B by means of four long screws P and the ring R; on the ring R screws the cap *s*, which covers the lower parts of the cistern, and supports at the end the adjusting-screw O. G, *i*, *j* and *k*, are of box-wood; the other parts of brass or German silver. The screw O serves to adjust the mercury to the ivory point, and also, by raising the bag, so as to completely fill the cistern and tube with mercury, to put the instrument in condition for transportation.

In Fortin's barometer, and also Delcro's modification of it, a cement is used to secure the mercury against leakage at the joints. This, sooner or later, is sure to give way; and tested under the extremes of the thermometrical and hygrometrical range of this climate especially, has made this defect more evident. This was removed by the substitution of iron in the place of wood; but it was soon found impracticable, in this form of cistern, to prevent damage from rust. These objections led to the present plan of construction, which effectually secures the joints without the use of any cement. The surfaces concerned are all made of a true figure, and simply clamped together by the screws, a very thin leather washer being interposed at the joints. This would not be permanent, however, but for the especial care taken in preparing the box-wood. The box-wood rings are all made from the centres of the wood and concentric with its growth. They are worked thin and then toughened, as well as made impervious to moisture, by complete saturation with shellac. This is effected by immersing them in a suitable solution in vacuo. The air being withdrawn from the pores of the wood, is replaced by the lac. This, however, with the after-drying or baking, requires care; but when properly done, the wood is rendered all but unchangeable.

Fig.6

Another peculiarity consists in making the scale adjustable to correct for capillarity, so that the barometer may read exactly with the adopted standard, without the application of any correction; and this, too, without destroying the character of the barometer as an original and standard instrument. Near the 30 inches line, figure 6, is a line *v*, on the main tube; this last line is distant exactly thirty inches from the tip of the ivory point; therefore, when these lines coincide, or make one line, the scale is in true measurement position; or the 30 mark is exactly thirty inches from the tip of the ivory point in the cistern. In this position, the amount of correction due to capillarity being ascertained, the scale is then moved that quantity and clamped firm. The barometer will now give the readings corrected for capillarity, and thus avoid at once the labor of applying a correction and the risk of error from an accidental neglect of it.

It must be borne in mind that this correction applies only to the particular tube, and while preserved in good condition.

If this tube is injured and again used, or another tube put in its place, the scale should then be moved until the lines coincide, the amount of correction for the repaired or the new tube being estimated until a good comparison can be made directly or intermediately with the Smithsonian standard.

The connecting the parts *i* and *j* by rings and screws, Figs. 2, 3, and 4, rather than by a single screw cut on the edge, is an improvement, as the single wood-screw is apt, after a time, to adhere so firmly that it is often difficult, and sometimes impossible with safety to the parts, to separate it.

It is not advisable to disturb the cistern unless it becomes difficult, from the oxide of mercury which gradually forms, to make the adjustment of the mercury to the ivory point, as there is more or less risk in doing so. Any one accustomed to such mechanical affairs, with due attention to the plan, can, however, take out the mercury from the cistern, refilter, clear the parts of adhering oxide, and replace them; the instrument all the time being kept vertical, with the cistern at top, as the mercury must not be allowed to come from the tube.

To insure a good vacuum by the complete expulsion of all air and moisture, the boiling of the mercury in the tube is done in vacuo; and care should be taken to preserve it in good condition.

To put up the barometer for observation, suspend the barometer by the ring A in a good light, near to and at the left side of a window, and, when practicable, in a room not liable to sudden variations of temperature. Record the temperature, and then, by the screw O, lower the mercury in the cistern until the surface is in the same plane with the extremity of the ivory point. As this extremity of the point is the zero of the scale, it is necessary, at each observation, to perfect this adjustment. It is perfect when the mercury just makes visible contact. If the surface is lowered a little, it is below the point; and if raised a small amount, a distinct depression is seen around the point. This depression is reduced to the least visible degree. A few trials will show that this adjustment can always be made to a thousandth of an inch.

The adjustment effected, bring the lower edge of the vernier C, Fig. 5, by means of the milled head D, into the same plane with the convex summit of the mercury in the tube. Looking through the opening, with the eye on a level with the top of the mercury in the tube, when the vernier tube is too low, the light is cut off; when too high, the light is seen above the top of the mercury. It is right when the light is just cut off from the summit, the edge making a tangent to the curve. A piece of white paper placed behind, and also at the cistern, will be found to give a more agreeable light by day, and is, besides, necessary for night observations; the lamp being placed before the instrument and above the eye, to reflect the light.

Fig 4.

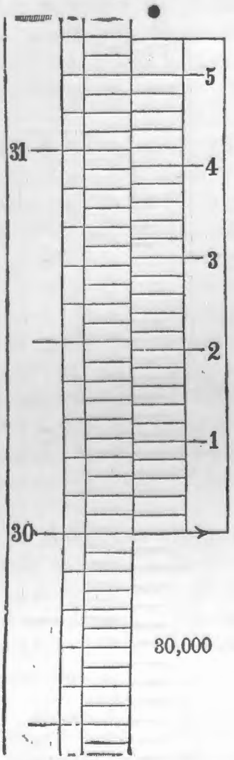
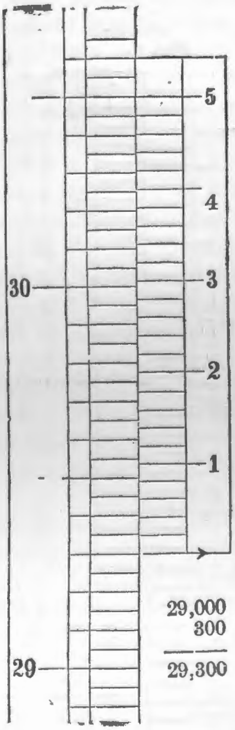


Fig. 5.



The method of reading off will perhaps be best explained by a few examples. Suppose, after completing the adjustments, the scale and vernier to be in the position shown in Fig. 4, on this page, it will be seen that the lowest or index line of the vernier coincides exactly with the line marked 30 on the scale. The reading, therefore, is 30.000 inches.

If, as in Fig. 5, we find the line of the vernier coinciding with the third line of the tenths above 29, we read 29.300.

If, as in Fig. 6. on this page, we find the index at 29 inches 3 tenths and 5 hundredths, 29.350.

If, as in Fig. 7, we find the index at 30 inches no tenths 5 hundredths and something more, this additional quantity we shall find by looking up the vernier scale until we come to some one line on it coinciding with a line on the other scale. In this instance it is the line marked 2, and indicates 2 hundredths, to be added to the other numbers, making 30.070.

Fig. 6.

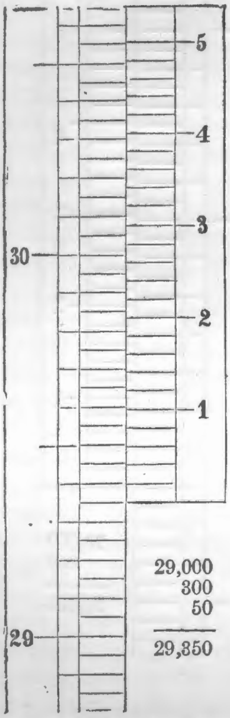
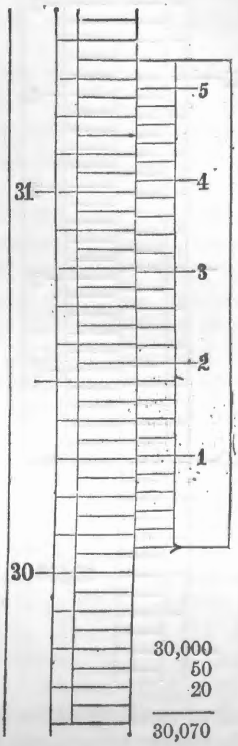


Fig. 7.



If, as in Fig. 8, we find 29 inches no tenths 5 hundredths, and on the vernier the second line above that marked 2, is found to coincide with the scale, each of these short lines indicates 2 thousandths—consequently are so counted; the reading is therefore 29.074.

Fig. 8.

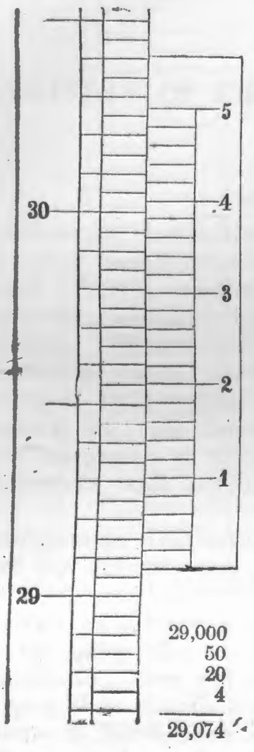
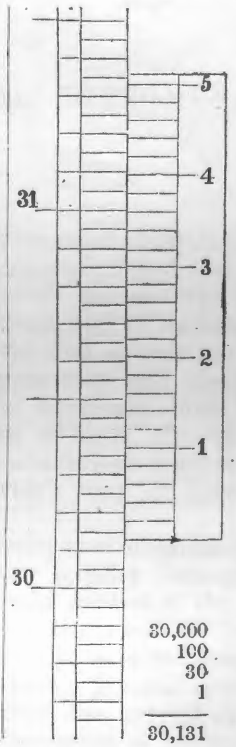


Fig. 9.



Or it may be, as in Fig. 9, where we have 30 inches 1 tenth, and the line on the vernier mark 3 coinciding nearly, but not perfectly, with a line on the scale, it is a little too high; the 2 thousandth short line next above is, however, a like quantity too low; so the true reading must be the number between them—that is, 1 thousandth, making together 30.131.

These examples include all the combinations the scale allows. A little practice with the barometer with reference to the examples will soon enable the learner to read off the scale with facility. At first it will be best to write down the inches and parts in full, as in the diagrams, not trusting the memory with the whole until experience shall have given confidence.

Be careful never to lower the mercury in the cistern much below the necessary quantity, as it increases the risk of air entering the tube.

When the barometer is to be removed for transportation or change of position, before taking it down, the mercury is to be screwed up until the cistern and tube are just full. If it is screwed more than this, the mercury may be forced through the joints of the cistern. It should then be inverted and carried cistern-end upwards.

This instrument is well adapted for service as a mountain barometer, and when used as such is packed in a leather case with suitable straps for convenient carriage.

METEOROLOGY.

REGISTRY OF PERIODICAL PHENOMENA.

The Smithsonian Institution, being desirous of obtaining information with regard to the periodical phenomena of animal and vegetable life in North America, respectfully invites all persons who may have it in their power, to record their observations, and to transmit them to the Institution. These should refer to the first appearance of leaves and of flowers in plants; the dates of appearance and disappearance of migratory or hybernating animals, as mammals, birds, reptiles, fishes, insects, &c.; the times of nesting of birds, of moulting and littering of mammals, of utterance of characteristic cries among reptiles and insects, and anything else which may be deemed noteworthy.

The Smithsonian Institution is also desirous of obtaining detailed lists of *all* the animals and plants of any locality throughout this continent. These, when practicable, should consist of the scientific names, as well as of those in common use; but when the former are unknown, the latter may alone be given. It is in contemplation to use the information thus gathered, in deducing general laws relating to the geographical distribution of species of the animal and vegetable kingdoms of North America. Any specimens of natural history will also be acceptable. Directions for their preservation have been published by the Institution, and will be sent to all who may wish them.

The points in the phenomena of plants, to which attention should be directed, are:

1. *Frondescence or Leafing.* When the buds first open and exhibit the green leaf.

2. *Flowering.* When the anther is first exhibited:
   a. In the most favorable location;
   b. General flowering of the species.

3. *Fructification.* When the pericarp splits spontaneously in dehiscent fruits, or the indehiscent fruit is fully ripe.

4. *Fall of leaf.* When the leaves have nearly all fallen.

The dates of these various periods should be inserted in their appropriate columns.

When the observations for the year are complete, they should be returned to the Institution, with the locality and observer's name inserted in the blank at the head of the sheet.

PLANTS.

List of plants.	Frondescence, or leafing.	Flowering.		Fructification.	Fall of leaf.
		a.	b.		
Acer rubrum, L.—Red, or soft maple					
Acer dasycarpum, Ehrh.—White, or silver maple					
Acer saccharinum, L.—Sugar maple					
Achillea millefolium, L.—Millefoil or yarrow					
Actæa rubra, Willd.—Red baneberry					
Actæa alba, Bigelow.—White baneberry; necklace weed					
Æsculus hippocastanum, L.—Horsechestnut					
Æsculus glabra, Willd.—Ohio buckeye					
Æsculus flava, Ait.—Yellow buckeye					
Ailantus glandulosa.—Tree of heaven; ailanthus					
Amelanchier canadensis.—Shad bush; service berry					
Amorpha fruticosa, L.—False indigo					
Amygdalus nana, L.—Flowering almond					
Anemone nemorosa, L.—Wind flower; wood anemone					
Aquilegia canadensis, L.—Wild columbine					
Arctostaphylos uva-ursi, Spreng.—Bearberry					
Asclepius cornuti, Decaisne.—Milkweed					
Asimina triloba, Dunal.—Papaw					
Azalea nudiflora, L.—Common red honeysuckle					
Bignonia (Tecoma) radicans, Juss.—Trumpet creeper					
Castanea vesca, L.—Chestnut					
Carya alba.—Shag-bark, or shell-bark hickory					
Cercis canadensis, L.—Red bud; Judas tree					
Cerasus virginiana, DC.—Chokeberry					
Cerasus serotina, DC.—Wild black cherry					
Chionanthus virginica, L.—Fringe tree					
Cimicifuga racemosa, Ell.—Black-snake root; rattlesnake root					
Claytonia virginica, L.—Spring beauty					
Clethra alnifolia.—White alder, or sweet pepper bush					
Cornus florida, L.—Flowering dogwood[*]					
Cratægus crus-galli, L.—Cockspur thorn					
Cratægus coccinea, L.—Scarlet-fruited thorn					
Cratægus oxycantha, L.—English hawthorn					
Epigæa repens, L.—Trailing arbutus; ground laurel					
Epilobium angustifolium, L.—Willow herb					
Erythronium americanum, Smith.—Dog-tooth violet, or adder's tongue					
Fraxinus americana, L.—White ash					
Gaylussacia resinosa, Torr. & Gray.—Black huckleberry					
Gerardia flava, L.—Yellow false foxglove					
Geranium maculatum, L.—Crane's bill					
Halesia tetraptera, Willd.—Snow-drop tree					

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[*] The time of the expansion of the real flower, not of the white involucre.

PLANTS—Continued.

List of plants.	Frondescence, or leafing.	Flowering.		Fructification.	Fall of leaf.
		a.	b.		
Hepatica triloba, Chaix.—Round lobed liverwort					
Houstonia cœrulea, Hook.—Bluets; innocence, &c					
Hypericum perforatum, L.—St. John's wort					
Iris versicolor, L.—Large blue flag					
Kalmia latifolia, L.—Mountain laurel					
Laurus benzoin, L.—(*Benzoin odoriferum*, Nees.) Spice bush; Benjamin bush					
Leucanthemum vulgare, Lam.—Ox-eye daisy; white weed					
Linnæa borealis, Gronov.—Twin flower					
Lobelia cardinalis, L.—Red cardinal flower					
Lonicera tartarica, L.—Foreign spurs					
Lupinus perennis, L.—Wild lupine					
Liriodendron tulipifera, L.—Tulip tree; American poplar					
Magnolia glauca, L.—Small or laurel magnolia; sweet bay					
Mitchella repens, L.—Partridge berry					
Morus rubra, L.—Red mulberry					
Nymphœa odorata, Ait.—Sweet-scented water lily					
Persica vulgaris, L.—Peach					
Podophyllum pellatum, L.—Mandrake; May-apple					
Pontederia cordata, L.—Pickerel weed					
Pogonio ophioglossoides, Nutt.—Adder's tongue					
Pyrus communis, L.—Common pear tree					
Pyrus malus, L.—Common apple tree					
Quercus alba, L.—White oak					
Rhododendron maximum, L.—Great laurel					
Ribes rubrum, L.—Currant					
Robinia pseud-acacia, L.—Common locust					
Robinia viscosa, Vent.—Clammy locust					
Rubus villosus, Ait.—Blackberry					
Sambucus canadensis, L.—Common elder					
Sambucus nigra, L.—Black elder					
Sanguinaria canadensis, L.—Blood root					
Sarracenia purpurea, L.—Side-saddle flower					
Saxifraga virginiensis, Michx.—Early saxifrage					
Smilacina bifolia, Ker.—Two-leaved Solomon-seal					
Syringa vulgaris, L.—Lilac					
Taraxacum dens-leonis, Desf.—Dandelion					
Tilia americana, L.—Bass wood; American lime, or linden					
Ulmus americana, L.—American elm					
Viburnum lentago, L.—Sweet viburnum					

BIRDS.

Birds.	Arrival in spring.	Commencement of nesting.	Commencement of incubation.	Appearance of young.	Departure in autumn.
Acanthylis pelasgia, Boie.—Chimney-bird					
Agelaius phœniceus, L.—Red-winged blackbird					
Anser canadensis, L.—Wild goose					
Hirundo purpurea, L.—Martin					
Hirundo rufa, L.—Barn swallow					
Pandion carolinus, Gm.—Fish-hawk					
Quiscalus ferrugineus, L.—Rusty blackbird					
Quiscalus versicolor, L.—Crow blackbird					
Sialia wilsonii, Sw.—Blue-bird					
Turdus migratorius, L.—Robin					
Tyrannula fusca, Sw.—Pewee					
Dolichonyx oryzivora, Sw.—Reed-bird, rice-bird, boblink					
Mimus felivox, Sw.—Cat-bird					
Tyrannus intrepidus, Vieill.—Ring-bird					
Troglodytes aedon.—House wren					
Antrostomus vociferous.—Whipporwill					

REPTILES—*first appearance, cries, and general peculiarities of habits.*

Bufo americanus, and other species of toads.
Rana, the various kinds of frogs.
Hyla and *Hylodes*, the several kinds of tree-frogs.
Turtles, lizards, snakes.

FISHES—*first appearance and spawning.*

Salmo salar, L., salmon.
Alosa, shad.
Clupea, herring.
Anguilla, eel.
Acipenser, sturgeon.

INSECTS—*their first appearance and cries.*

Platyphyllum concavum, Harr., catydid.
Cicada, locusts—the several kinds.
Œcanthus niveus, Harr., tree-crickets.
Grasshoppers, in their variety.
Fire-flies.

GENERAL PHENOMENA OF CLIMATE.

Phenomena of a general character, of which the date of appearance cannot be mistaken, are very valuable. Series of years have in some cases been carefully observed, which would greatly add to the value of the current record if forwarded with it. The following are of this class:

1. Breaking up of ice in large rivers or bays.
2. Date of greatest rise and lowest fall of water in large rivers, especially when periodic, as in parts of the interior.
3. General leafing and fall of leaf in deciduous forests. In most parts of the North and interior these are well marked and easily designated periods.
4. Commencement of growth and the end of growth or destruction of grasses in general; as on plains or prairies.
5. First growth, flowering, and maturity, of important annual staples, with their period in days from the commencement to the end of vital action.

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[illegible]

sometimes [illegible] apparent [illegible] character [illegible] and [illegible] that [illegible]

[illegible]

times [illegible] to [illegible] are [illegible]

[illegible]

In [illegible] curate [illegible] Selections [illegible] view of the [illegible] able [illegible] beats [illegible] periodic [illegible] electric [illegible] of the [illegible] thunder, in [illegible] by [illegible] visibility [illegible]

METEOROLOGY.

OBSERVATIONS ON THUNDER AND LIGHTNING.

BY STILLMAN MASTERMAN,
WELD, FRANKLIN COUNTY, MAINE.

The following observations on the duration of peals of thunder were made for the purpose of verifying an assumption of my own, that the limit usually assigned to the continuation of the rolling of thunder is too low. I find that in some instances the rolling sound of the thunder lasts several seconds longer than what meteorologists have generally given as its extreme duration. In observing the sound accompanying discharges of atmospheric electricity, a great variety is apparent, not only in duration, but also in intensity and general character. It would be futile to attempt to give all the gradations and tones under which this sound is presented to the ear; but I find that it is conveniently divisible into *four* general classes, as follows:

1. That which commonly commences with not a very great force, and increases, generally somewhat regularly, up to its maximum intensity, and then decreases until reaching its termination. Sometimes the maximum occurs at or near the commencement of the sound, and again as near its termination. This is the more common class of thunder.

2. That which commences with a sound of moderate force and continues throughout its entire duration with but a slight variation in intensity. In the annexed tables of observations, peals of this class are designated by the word "*uniform.*"

3. That which presents a sound alternately very loud and low, in rapid succession; sometimes having rapidly succeeding maxima and minima during its whole continuation. I designate peals of this class by the word "*vibratory.*"

4. This class comprises those claps of thunder which have but a momentary duration, like the sound of a cannon, fired where nothing can reflect the sound as an echo. I distinguish claps of this class by the term "*momentary.*"

In making the annexed observations, I used in most cases an accurate solar clock beating seconds, by which to note divisions of time. Selecting such a position near the clock as to have an unobstructed view of the quarter of the heavens occupied by the storm, and to be able to catch the least audible sound of thunder, I could count the beats of the pendulum, either by the clicking, or, if necessary, by its perceivable motion. In cases of peals of thunder preceded by visible electric discharges, I commence to count the seconds from the flashing of the lightning; noting the first audible instant of sound of the thunder, its maximum intensity, and its last moment of audibility, by marking their respective number of seconds from the instant of visibility of the lightning. In peals not preceded by visible lightning which could be identified, I have commenced to reckon time from the first instant of audibility of the sound.

As will be observed, the annexed observations were made, some at Weld, Franklin county, Maine, and the others at Stillwater, Minnesota Territory.

A.

Weld, Franklin County, Maine.—Thunder-storm in the afternoon of the 16th of August, 1850.

Observed the duration of a single peal of thunder, as follows:

Lightning flashed	0 seconds.
Thunder first audible	10 "
loud	13 "
very loud	15 "
loudest	20 "
very loud	30 "
loud	40 "
becomes inaudible	61 "
Entire duration of the sound, or rolling of the thunder	51 "

B.

Stillwater, Minnesota Territory.—Thunder-storm in the morning of June 24, 1851.

OBSERVATIONS.

Order of peals	α	β	γ	δ
	s.	s.	s.	s.
Lightning flashed	0	0	0	0
Thunder first audible	9	4	10	10
loud		5		20
loudest	15	7	14	22
loud		8		24
becomes inaudible	40	20	40	28
duration of rolling of	31	16	30	18

C.

Stillwater, Minnesota Territory.—Thunder-storm in the afternoon of August 11, 1851.

OBSERVATIONS.

Order of peals	α	β	γ	δ	ε	ζ	η	θ
	s.	s.	s.	s.	s.	s.	s.	s.
Lightning flashed	0	0	0	0	0	0	0	0
Thunder first audible	No thunder audible within 2 minutes' time.	3 min. elapsed without audible sound.	27	14	29	Without audible thunder.	Without audible thunder.	Without audible thunder.
loud			Uniform.					
loudest				30	37			
loud					82			
becomes inaudible			32	35	85			
duration of			5	21	56			

D.

Stillwater, Minnesota Territory.—Thunder-storm in the morning of July 5, 1852.

OBSERVATIONS.

Order of peals	α	β	γ	δ	ε	ζ	η	θ
	s.	s.	s.	s.	s.	s.	s.	s.
Lightning flashed	0	0	0	0	0	0	0	0
Thunder first audible	8	12	6	12	10	8	22	10
loudest	(°)	(†)	20	(‡)	------	20	30	(‡)
becomes inaudible	34	(†)	24	26	37	28	50	26
duration of	26	(†)	18	14	27	20	28	16

° Uniform. † Momentary. ‡ Vibratory.

Remarks.—η, thunder very heavy. A continual flickering of lightning succeeded the above observations; but the sound of the falling rain prevented the thunder being heard, only when of uncommon loudness.

E.

Weld, Franklin County, Maine.—Thunder-storm in the afternoon of May 16, 1853.

OBSERVATIONS.

Order of peals	α	β	γ		ε	ζ	η	θ
	s.	s.	s.	s.	s.	s.	s.	s.
Lightning flashed	------	------	0	------	------	------	------	------
Thunder first audible	0	0	34	0	0	0	0	0
loudest	28	(°)	45	------	------	------	------	4
becomes inaudible	40	15	60	10	15	14	30	8
duration of	40	15	26	10	15	14	30	8
Order of peals	ι	χ	λ	μ	ν	ξ	ο	π
	s.	s.	s.	s.	s.	s.	s.	s.
Lightning flashed	------	------	------	------	------	------	------	------
Thunder first audible	0	0	0	0	0	0	0	0
loudest	------	------	------	------	------	------	------	------
becomes inaudible	18	12	10	8	12	13	13	10
duration of	18	12	10	8	12	13	13	10

° Uniform.

Remarks.—The lightning was either invisible or could not be identified before fifteen of these sixteen peals of thunder.

F.

Weld, Franklin County, Maine.—Thunder-storm in the afternoon of September 6, 1853.

OBSERVATIONS.

Order of peals	α	β	γ	δ	ε	ζ	η	θ	ι	κ	
	s.	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*
Lightning flashed	----	----	----	----	----	----	----	----	----	0	----
Thunder first audible	0	0	0	0	0	0	0	0	0	11	0
loud	----	----	----	----	----	----	----	----	----	----	----
loudest	----	----	----	12	6	15	----	----	20	34	15
loud	----	----	----	----	----	----	----	----	45	----	----
becomes inaudible	30	12	30	33	28	50	28	60	61	50	29
duration of	30	12	30	33	28	50	28	60	61	39	29

Order of peals	μ	ν	ξ	ο	π	ρ	σ	τ	υ	φ	χ
	s.	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*
Lightning flashed	0	----	0	----	0	----	----	----	----	0	----
Thunder first audible	14	0	27	0	15	0	0	0	0	20	0
loud	----	----	----	----	----	----	----	----	----	----	----
loudest	21	10	----	----	25	----	----	----	10	30	3
loud	----	----	----	----	----	----	----	----	----	----	----
becomes inaudible	50	15	50	15	41	15	7	37	15	43	7
duration of	36	15	23	15	26	15	7	37	15	23	7

Order of peals	ψ	ω	α′	β′	γ′	δ′	ε′	ζ′	η′	θ′	ι′
	s.	*e.*	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*
Lightning flashed	0	0	0	----	0	0	0	----	0	0	0
Thunder first audible	20	20	13	0	9	12	13	0	10	17	30
loud	----	----	----	----	----	----	----	----	----	24	33
loudest	30	36	36	13	25	15	----	----	----	50	62
loud	----	----	----	----	----	----	----	----	----	----	----
becomes inaudible	42	50	40	23	60	42	29	35	23	55	75
duration of	22	30	27	23	51	30	16	----	13	38	45

REMARKS.—As will be seen, only fourteen out of the above thirty-three claps of thunder were preceded by lightning which could be identified as that producing the audible sound.

G.

Weld, Franklin County, Maine.—Thunder-storm in the afternoon of September 7, 1853.

OBSERVATIONS.

Order of peals	α	β	γ	δ	ε	ζ	η	θ	ι	κ	λ	μ	ν	ξ
	s.	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*
Lightning flashed	----	----	----	----	----	----	----	----	----	----	----	0	----	----
Thund. first audible	0	0	0	0	0	0	0	0	0	0	0	8	0	0
loud	----	----	----	----	----	----	----	----	----	10	----	10	----	----
loudest	30	34	10	9	28	15	16	8	8	11	10	12	12	8
loud	----	----	24	----	----	----	----	----	----	----	18	----	----	----
becomes inaudible	38	36	30	12	32	25	28	15	18	20	20	22	25	12
duration of	38	36	30	12	32	25	28	15	18	20	20	14	25	25

Order of peals	ο	π	ρ	σ	τ	υ	φ	χ	ψ	ω	α′	β′	γ′	δ′
	s.	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*
Lightning flashed	----	----	----	----	----	----	----	----	----	----	----	0	----	----
Thund. first audible	0	0	0	0	0	0	0	0	0	0	0	37	0	0
loud	9	12	15	7	30	13	7	4	4	7	25	39	----	----
loudest	12	15	17	15	37	15	17	7	10	15	33	44	9	25
loud	15	20	23	34	----	17	24	----	----	25	38	45	----	----
becomes inaudible	17	30	25	37	58	33	30	13	22	40	45	56	17	31
duration of	17	30	25	37	58	33	30	13	22	40	45	19	17	31

H.

Weld, Franklin County, Maine.—Thunder-storm in the afternoon of May 21, 1854.

OBSERVATIONS.

Order of peals	α	β		δ	ε
	s.	*s.*	*s.*	*s.*	*s.*
Lightning flashed	----	0	----	0	----
Thunder first audible	0	20	0	7	0
loudest	3	46	8	25	----
becomes inaudible	10	60	15	40	15
duration of	10	40	15	33	15

Remark.—δ, thunder very heavy.

I.

Weld, Franklin County, Maine.—Thunder-storm in the afternoon of June 9, 1854.

OBSERVATIONS.

Order of peals	α	β	γ	δ	ε	ζ	η	θ	ι	κ	λ
	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.
Lightning flashed	----	----	----	----	----	----	----	----	----	0	0
Thunder first audible	0	0	0	0	0	0	0	0	0	0	10
loud	12	----	----	----	----	1	6	----	35	10	24
loudest	26	8	6	----	----	3	10	12	40	12	38
loud	----	----	----	----	----	----	11	----	*45	(†)	†39
becomes inaudible	30	16	8	10	8	6	13	25	48	16	45
duration of	30	16	8	10	8	6	13	25	48	16	35

Order of peals	μ	ν	ξ	ο	π	ρ	ς	τ	υ	φ	χ
	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.
Lightning flashed	0	0	0	----	0	0	0	0	0	0	0
Thunder first audible	21	5	3	0	1	13	15	20	15	10	10
loud	----	----	8	6	----	----	----	(‖)	----	14	15
loudest	41	19	10	10	2	23	26	(‖)	35	28	19
loud	(†)	(†)	(*)	----	(‡)	(§)	----	(‖)	(*)	¶29	*20
becomes inaudible	45	25	12	11	12	40	30	40	49	35	40
duration of	24	20	9	11	11	27	15	20	34	25	30

* Very loud.
† Very heavy.
‡ Very sharp and heavy.
§ Loud.
‖ Uniform and loud.
¶ Extremely heavy.

J.

Weld, Franklin County, Maine.—Second thunder-storm in the afternoon of June 9, 1854.

OBSERVATIONS.

Order of peals		β	γ	δ	ε	ζ	η	θ
	s.	s.	s.	s.	s.	s.	s.	s.
Thunder first audible	0	0	0	0	0	0	0	0
loud	18	12	28	18	18	18	45	20
loudest	36	18	88	53	20	28	60	25
loud	----	----	----	----	----	35	----	65
becomes inaudible	50	66	65	80	44	50	80	70
duration of	50	66	65	80	44	50	80	70

REMARKS.—Storm had passed over to the southeast. The rolls of thunder, however long, appeared to be distinct peals, occurring at intervals of some minutes. Thunder was very loud. No lightning was seen which could be ascribed to the above peals.

K.

Weld, Franklin County, Maine.—Thunder-storm at noon on June 13, 1854.

OBSERVATIONS.

Order of peals	α	β	γ	δ	ε	ζ	η
	s.	s.	s.	s.	s.	s.	s.
Thunder first audible	0	0	0	0	0	0	0
loudest	6	12	8	6	2	3	8
becomes inaudible	14	13	18	15	20	20	18
duration of	14	13	18	15	20	20	18

REMARKS.—A small thunder-cloud immediately overhead, with a slight spray of rain. No lightning seen. The claps of thunder following one another after intervals of a minute or two.

L.—*Weld, Franklin County, Maine.—Thunder-storm in the afternoon of June* 14, 1854.

OBSERVATIONS.

Order of peals	α	β	γ	δ	ε	ζ	μ	θ	ι	κ	λ	μ	ν	ξ	ο	π	ρ	σ	τ
	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.
Lightning flashed			0							0								0	
Thunder first audible	0	0	20	0	0	0	0	0	0	31	0	0	0	0	0	0	0	43	0
loud			40		8		12		8	40		21	5	22	22			58	
loudest	8	8	45	35	28	9	21	32	10	56	40	41	15	23	40	18	20	61	21
loud			48				32			60			17					63	
becomes inaudible	15	35	50	40	33	10	38	40	30	68	43	44	30	30	62	48	40	86	22
duration of	15	35	30	40	33	10	38	40	30	37	43	44	30	30	62	48	40	43	22

Order of peals	υ	φ	χ	ψ	ω	α^1	β^1	γ^1	δ^1	ε^1	ζ^1	η^1	θ^1	ι^1	κ^1	λ^1	μ^1	ν^1
	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s	s.	s.	s.	s.	s.	s.	s.
Lightning flashed																		
Thunder audible	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
loud	33			20	(✲)		2	2	2		5			4	4		15	3
loudest	34	13	9	54	(✲)	15	59	3	54	14	30	18	4	20	10	8	37	4
loud					(✲)	20	61											
becomes inaudible	58	47	15	60	65	26	75	4	55	15	39	20	25	25	15	20	42	30
duration of	58	47	15	60	65	26	75	4	55	15	39	20	25	25	15	20	42	30

✲ Uniform.

REMARKS.

γ Very heavy thunder.
μ Thunder heavy.
μ^1 Very heavy thunder.
σ Lightning very sharp. Thunder uncommonly heavy.
This storm passed with little rain at our place.

κ Lightning sharp. Thunder very heavy.
α^1 Thunder very heavy.
η Heavy thunder.
κ^1 Heavy thunder.

M.

Weld, Franklin County, Maine.—Thunder-storm in the afternoon of June 15, 1854.

OBSERVATIONS.

Order of peals	α	β	γ	δ	ε	ζ	η	θ	ι	κ	λ	μ	ν	ξ	ο	π	ρ
	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.
Lightning flashed	....	....	....	....	....	....	....	....	....	0	....	0	0	0	0	0	0
Thunder first audible	0	0	0	0	0	0	0	0	0	18	0	10	9	13	10	9	11
loud	....	....	8	1	2	3	....	3	30	....	8	....	13	38	12	10	12
loudest	8	2	18	2	4	25	23	5	38	19	10	18	15	50	12	20	15
loud	....	....	....	....	....	....	....	....	....	....	....	....	22	....	....	....	....
becomes inaudible	20	20	28	10	20	39	....	23	40	33	....	30	34	60	13	28	25
duration of	20	20	28	10	20	39	....	23	40	15	....	20	25	47	3	19	14

Order of peals	σ	τ	υ	φ	χ	ψ	ω	α′	β′	γ′	δ′	ε′	ζ′	η′	θ′	ι′	κ′
	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.
Lightning flashed	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thunder first audible	8	10	8	8	8	10	1	2	9	5	5	5	10	11	3	5	14
loud	12	11	14	12	9	....	....	4	15	5	....	....	11	....	....	....	(*)
loudest	15	14	15	18	10	13	2	5	15	8	20	12	16	....	10	10	(*)
loud	....	....	....	....	....	....	....	8	....	16	....	....	....	....	....	13	(*)
becomes inaudible	20	16	20	20	15	15	10	15	20	22	21	15	20	....	25	28	38
duration of	12	6	12	12	7	5	9	13	11	17	16	10	10	....	22	23	24

* Uniform.

M—Continued.

Order of peals	λ'	μ'	ν'	ξ'	ο'	π'	ρ'	σ'	τ'	υ'	φ'	χ'	ψ'	ω'	α''	β''	γ''
	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.
Lightning flashed	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thunder first audible	6	4	4	4	3	4	8	9	5	4	6	8	4	5	4	8	3
loud	10	----	10	----	----	----	----	----	----	----	----	----	----	----	----	----	----
loudest	12	----	12	18	4	8	10	11	----	----	----	----	----	5	8	12	7
loud	15	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
becomes inaudible	20	----	23	22	5	12	12	20	----	----	----	----	----	12	10	20	15
duration of	14	----	19	18	2	8	4	11	----	----	----	----	----	7	6	12	12

Order of peals	δ''	ε''	ζ''	η''	θ''	ι''	κ''	λ''	μ''	ν''	ξ''	ο''	π''	ρ''	σ''	τ''
	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.
Lightning flashed	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thunder first audible	5	8	2	13	1	2	9	8	4	11	9	10	14	12	11	9
loud	----	----	----	----	----	----	----	----	----	----	12	----	----	----	----	----
loudest	8	10	12	20	2	3	----	8	----	----	25	----	33	13	12	10
loud	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
becomes inaudible	----	20	15	----	----	----	----	20	----	35	33	----	37	24	37	40
duration of	----	12	13	----	----	----	----	12	----	24	24	----	23	12	26	31

M—Continued.

Order of peals	ν″	φ″	χ″	ψ″	ω″	α‴	β‴	γ‴	δ‴	ε‴	ζ‴	η‴	θ‴	ι‴	κ‴	λ‴
	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.
Lightning flashed	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thunder first audible	9	12	8	8	8	10	13	7	12	15	13	14	15	----	----	----
loud	----	15	9	----	----	----	----	----	18	----	22	16	18	----	----	----
loudest	22	16	15	----	----	21	----	16	24	----	25	21	25	----	----	----
loud	----	20	----	----	----	----	----	21	----	----	----	----	----	----	----	----
becomes inaudible	33	30	33	39	----	43	----	41	50	----	40	50	35	----	----	----
duration of	24	18	25	31	----	33	----	34	38	----	27	36	20	----	----	----

REMARKS.

This was a severe thunder-storm. Many buildings, trees, and other objects in our town were struck by the electric discharges.

γ and ν. Thunder very heavy.
ξ π ρ and σ. Lightning very sharp; thunder very heavy.
υ. A gush of rain immediately preceded the lightning.
φ χ and ψ. Thunder extremely heavy.
ω. This discharge struck a barn about one-fifth of a mile distant; lightning vivid; thunder extremely loud.

α′ and β′. Lightning vivid; thunder almost deafening.
ν and σ. Thunder loud.
χ′. Gush of rain preceded the lightning.
λ′ η′ and ν′. Very heavy thunder following vivid lightning.
θ′ and ι′. Vivid lightning; extremely loud thunder.
φ. Extremely loud and heavy thunder.

N.

Weld, Franklin County, Maine.—Thunder-storm in the afternoon of July 4, 1854.

OBSERVATIONS.

Order of peals	α	β	γ	δ	ε	ζ	η	θ	ι	κ	λ	μ	ν	ξ	ο	π	ρ	σ	τ	υ	φ
	s.	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*	*s.*
Lightning flashed	0	----	0	0	----	0	0	0	----	0	0	0	0	0	0	0	0	0	0	0	0
Thunder first audible	50	0	38	28	0	12	8	11	0	15	2	4	5	7	10	13	12	16	13	28	38
loud	----	----	----	(*)	----	----	----	(*)	----	----	----	----	----	----	----	----	----	----	----	----	----
loudest	56	10	39	(*)	10	14	10	(*)	5	20	----	5	7	9	25	38	----	40	34	30	----
loud	74	----	----	(*)	----	----	----	(*)	----	----	----	----	----	----	----	----	----	----	48	----	----
becomes inaudible	80	18	40	40	15	30	20	15	8	25	----	10	15	12	38	40	----	45	55	60	----
duration of	30	18	2	12	15	18	12	4	8	10	----	6	10	5	28	27	----	29	42	32	----

* Uniform.

REMARKS.

α. Very heavy.
β. Heavy thunder.
λ. Thunder very sharp and heavy. This discharge struck a house about one-half a mile distant—passing through the building in two paths.

O.

Weld, Franklin County, Maine.—Thunder-storm in the afternoon of July 9, 1854.

OBSERVATIONS.

Order of peals	α	β	γ	δ	ε	ζ	η	θ	ι	κ	λ	μ	ν	ξ	ο	π	ρ	σ
	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.
Lightning flashed	----	----	----	0	----	----	----	0	0	----	----	0	0	0	0	----	0	0
Thunder first audible	0	0	0	17	0	0	0	16	20	0	0	14	13	18	13	0	11	15
loud	----	----	----	----	----	----	----	17	----	----	----	19	----	----	----	----	----	----
loudest	3	4	3	19	2	10	3	20	21	2	1	22	23	27	18	22	20	30
loud	----	----	----	----	----	----	----	----	----	----	4	----	----	----	----	----	----	----
becomes inaudible	4	7	9	31	5	13	5	30	30	7	6	28	25	36	35	30	25	35
duration of	4	7	9	14	5	13	5	14	10	7	6	14	12	18	22	30	14	20

Order of peals	τ	υ	φ	χ	ψ	ω	α′	β′	γ′	δ′	ε′	ζ′	η′	θ′	ι′	κ′	λ′	μ′
	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.
Lightning flashed	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	----	----	----
Thunder first audible	20	8	19	12	12	8	13	13	2	15	15	13	9	32	27	0	0	0
loud	----	9	----	27	----	----	----	----	----	----	----	----	----	38	35	----	----	7
loudest	30	12	31	27	29	18	25	15	3	20	18	31	23	45	35	----	17	21
loud	----	----	31	----	----	----	----	----	----	----	----	----	----	----	----	----	----	25
becomes inaudible	40	30	35	33	35	30	----	39	----	30	35	----	48	65	41	28	20	27
duration of	20	22	16	21	23	22	----	26	----	15	20	----	39	33	14	28	20	27

O—Continued.

Order of peals	ν′	ξ′	ο′	π′	ρ′	σ′	τ′	υ′	φ′	χ′	ψ′	ω′	α″	β″	γ″	δ″	ε″	ζ″
	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.
Lightning flashed	----	----	----	----	----	----	----	----	----	----	0	0	0	0	0	0	0	0
Thunder first audible	0	0	0	0	0	0	0	0	0	0	9	12	12	15	14	12	10	14
loud	----	(*)	(*)	(*)	----	----	----	----	----	----	15	----	22	(*)	12	22	(*)	(*)
loudest	12	(*)	(*)	(*)	3	8	5	13	3	----	17	18	24	(*)	20	28	(*)	(*)
loud	----	(*)	(*)	(*)	----	----	----	----	----	----	19	----	----	(*)	----	----	(*)	(*)
becomes inaudible	23	29	18	18	20	28	16	18	20	40	34	38	30	30	35	56	50	40
duration of	23	29	18	18	20	28	16	18	20	40	25	26	18	15	21	44	40	26

* Uniform.

REMARKS.

ε.	Lightning preceded by gush of rain.
φ, ψ, & ω.	Very heavy thunder.
θ′ & ι′.	Lightning very sharp.
γ″.	Very heavy thunder.
η.	Thunder heavy.
θ, μ, ζ, & τ.	Heavy thunder.
γ′.	Lightning sharp; thunder very heavy.
μ′.	Thunder very heavy.
ψ′.	Extremely heavy.
ζ″.	Moderately heavy.

P.

Weld, Franklin County, Maine.—Thunder-storm of September 6, 1854.

OBSERVATIONS.

Order of peals	α	β	γ	δ	ε	ζ	η	θ
	s.	s.	s.	s.	s.	s.	s.	s.
Lightning flashed	0	0	0	0	0	0	0	0
Thunder first audible	10	14	13	------	------	12	14	11
loud	------	------	------	------	------	------	------	----
loudest	11	------	------	------	------	30	22	34
loud	------	------	------	------	------	------	------	40
become inaudible	55	------	------	------	------	------	40	66
duration of	45	------	------	------	------	------	26	55

REMARKS.

α. Thunder very heavy.
δ. Preceded by a gush of rain five seconds before the flashing of the lightning.
ε. Lightning preceded by gush of rain one second.
η. Extremely heavy thunder.
θ. Lightning vivid; thunder extremely heavy and loud, causing the ground to tremble.

SUMMARY RECAPITULATION.

1. *Peals of thunder preceded by visible lightning.*

Average duration of interval between the flashing of the lightning and the first audibility of the thunder, in one hundred and seventy-five (175) cases observed .... 12.32 seconds.
Minimum ditto...... (π—I and ω & θ″ — M)....... 1.00 "
Maximum ditto...... (a — N).......................... 50.00 "

Average duration of interval between the flashing of the lightning and the last audibility of the thunder, in one hundred and forty-eight (148) cases observed.. 34.70 seconds.
Minimum ditto......(σ′ — M) .... 5.00 "
Maximum ditto......(σ — L)............................ 86.00 "

Average duration of the interval between the first audibility of the thunder, and the last audibility of the same, or the length of the peals, in the one hundred and forty-eight (148) cases observed .... 21.85 seconds.
Minimum ditto......(σ′ — M and γ — N) .... 2.00 "
Maximum ditto......(ε — C) .... 56.00 "

2. *Peals of thunder not preceded by visible lightning.*

Average duration of the interval between the first and last audibility of the thunder, or the entire lengths of the peals, in one hundred and fifty-six (156) cases observed........... 26.60 seconds.
Minimum ditto......(γ — L and α — O) .... 4.00 "
Maximum ditto......(η — J)........................... 80.00 "

PHENOMENA OF LIGHTNING.

1. *Lightning without visible clouds.*

Weld, Me., May 28, 1850.—At 9 o'clock in the evening, vivid flashes of lightning appeared above the western horizon, while not a cloud was to be seen in the visible concave. The stars shone brilliantly, and I could readily distinguish those of the 5th magnitude immediately above the western hills, whence the lightning appeared to emanate. The sky in that quarter was vividly illuminated by the lightning at least fifty times during five or ten minutes.

Stillwater, Minnesota Territory, July 20, 1852.—Being out in the open air, in the evening, I observed a sudden flash of lightning which was followed by several succeeding flashes, occurring once in every few moments. No thunder was heard. The flashes of lightning were quite vivid and had a flickering appearance; but they seemed to emanate from no particular quarter of the sky, being diffused over the whole visible arena. At the time, but a few clouds could be seen, most of these being small, thin, and fleecy; and the sky presented a dingy or hazy ground, particularly so near the horizon. Along the northwestern horizon lay a small stratum of clouds, but they presented no appearance of being the seat of the electric discharges; on the other hand they remained quite dark during the several flashes. At daybreak on the succeeding morning, we experienced a smart thunder-storm.

Weld, Me., May 28, 1853.—In the evening the sky was very clear; not a single cloud was to be seen in any quarter. While out in the open air, between 9 and 10 o'clock, I observed a great number of vivid flashes of lightning. I could not discern that the lightning proceeded from any particular part of the sky. The sky was slightly smoky or dingy near the horizon.

2. *Cuspidated lightning.*

Weld, Me., June 7, 1850.—At 6 o'clock p. m. we experienced a heavy thunder-storm. When the storm had passed a little to the eastward *tri-cuspidated* lightning was exhibited; that is to say, the electric discharge emanated from the clouds as a single chain, but soon divided, approaching the earth in three different lines. After the lapse of a few minutes I observed *four* distinct streams of the electric fluid to emanate from the same point and at the same time, and pursue as many different paths to the earth.

Prairie west of Freeport, Illinois, May 30, 1851.—Being out in the open air in the evening, during a severe thunder-storm, I observed *bi-cuspidated* and also *tri-cuspidated* electric discharges.

Stillwater, Minnesota Territory, July 4, 1852.—At 8 o'clock p. m., there was a large body of thunder-clouds just above the eastern horizon, on the north side of which were two horn-like projections extending outward parallel with the horizon and each other to the extent of about 12°, and being about the same distance apart. There were frequent discharges of zigzag lightning passing between these horns, projected on a clear sky, as a back-ground. In one instance, two chains of electric fluid were seen to leave the upper one simultaneously 3° apart, and unite on reaching the lower cloud.

3. *Curvated electric discharges.*

In the thunder-storm of June 7, 1850, when the storm lay to the eastward, an electric spark passed from the eastern cloud to one in the western sky, apparently in a curvated path. During a thunder-storm occurring on the 30th of June last, (1856,) I observed an electric spark to describe a semi-circular arc; the chord or diameter of the arc being 45° in extent, parallel with and near to the horizon.

4. *Miscellaneous electric phenomena.*

During the thunder-storm on the prairie west of Freeport, Illinois, on May 30, 1851, a ball of electric fluid apparently emanated from a cloud, and after a few seconds burst, sending brilliant corruscations over the entire vault above.

Stillwater, *Minnesota*, *September* 1, 1851.—In the evening, a small cluster of columnar-shaped clouds rested on the horizon in the southeast, their height being about 15°. Their outlines were distinctly visible in the light of the lunar orb. As I was contemplating these clouds, I observed vivid lightning appear from their upper edge, about midway of the cluster. The lightning appeared like an intensely brilliant disk exactly round, and about 2° in diameter, but of no longer duration than an ordinary electric flash. This was succeeded in a few seconds by another exactly similar flash, which was followed by several others; the disk of light appearing the same at each succeeding flash, with the exception that it continually decreased in diameter, so that at the end of twenty minutes it presented the apparent size of the sun. Shortly after this, two other similar disks of light would appear simultaneously with the first observed, and about 20° on each side of it. After the last named phenomenon occurred, at about ten succeeding flashes, the central disk sent out at each glow vivid chains of lightning which were projected far on the sky above.

Stillwater, *Minnesota*, *June* 14 *and* 15, 1852.—On the evening of the 14th, and morning of the 15th, there was a slight thunder-storm. I noticed that for several succeeding discharges of the electric fluid, there was in every instance a sudden and violent gush of rain immediately *previous* to the flashing of the lightning. I have observed a like phenomena on other occasions.

Stillwater, *Minnesota*, *July* 21, 1852.—In the morning, just after daybreak, we had a fine thunder-storm. While the storm was yet coming up from the west I observed a vivid discharge of electricity dart from the overhanging cloud to the southeastern horizon, where a very slight spray of rain was falling at the time. There were no clouds visible in that part of the sky beneath the one overhead. No thunder was audible within five or ten minutes of the electric discharge, and the first heard appeared to be located in the opposite direction.

A phenomenon of thunder.

Weld, Me., *July* 18, 1854.—At sunrise in the morning, I heard repeated peals of heavy thunder while no clouds were visible above the horizon. The thundering continued for several hours. For some time not a single cloud was visible, yet the thunder was very heavy; occurring at intervals of a few minutes. At last, a few flying *cumuli* appeared, but none from which thunder could proceed. No thunder-clouds were visible during the day. It could not have been any other sound mistaken for that of thunder; for the peals were prolonged rolls, sometimes nearly one-half a minute in length, having their maxima and gradations like common peals of distant thunder. I could not determine satisfactorily from which direction the sound proceeded. Afterwards, however, I learned that the thunder-storm was to the east of us. At a village eight or ten miles east of us on the morning named above, a thunder-storm was visible low down in the eastern horizon, which darted forth vivid flashes of lightning, and gave out heavy peals of thunder.

EXTRACTS

FROM

THE CORRESPONDENCE

OF THE

SMITHSONIAN INSTITUTION.

Sketch of the Navajo Tribe of Indians, Territory of New Mexico, by Jona. Letherman, Assistant Surgeon U. S. Army.

The Navajo Indians are a tribe inhabiting a district in the Territory of New Mexico, lying between the San Juan river on the north and northeast, the Pueblo of Zuñi on the south, the Moqui villages on the west, and the ridge of land dividing the waters which flow into the Atlantic ocean from those which flow into the Pacific on the east—giving an area of about twelve thousand (12,000) square miles. The Navajoes can muster from twenty-five hundred (2,500) to three thousand (3,000) mounted warriors.

The great and distinguishing feature of the country occupied by these people is the mountains. The entire country is composed of them and the intervening valleys—their general direction being north and south, with slight eastwardly and westwardly variation. They are broken in many places into deep ravines and cañons, which, for the most part, run perpendicularly to the general direction of the mountain. These cañons afford, in many places, the only means of traversing the country, unless with great difficulty and labor. On their eastern aspect, these mountains present a slope which can be ascended without much trouble, having an angle of elevation of twenty, twenty-five, or thirty degrees; but on the western side the descent is generally abrupt and often impassable, presenting a perpendicular wall of rock from three hundred (300) to four hundred (400) or more, feet in height. The top of the mountain is frequently leve to a great extent, forming the table-land, or mesas, in the parlance of the Mexicans. The appearance, looking west from the top of a high mountain, is that of a succession of comparatively gentle slopes, rising one after another. Looking east from the same mountain a series of high escarpments is seen as far as vision extends. These mountains are chiefly composed of sandstone—rocks, in all probability, belonging to the period of the "new-red sandstone" and carboniferous formation. It is generally soft and friable; some, however, being found suitable for building purposes in this altitude and climate, but not for the lower and more humid portions of the United States, east of the Territory of New Mexico. Some limestone, of a very impure quality, is found in various localities, but it is exceedingly difficult to reduce, requiring from ten to fifteen days for its calcination. Sulphate of lime, conglomerate, and in some places bituminous coal, exist. Pyropes, of a fine quality, are seen in different portions of the country, but they are generally small—the largest ever seen at Fort Defiance weighing one hundred and twenty (120) grains. Masses of lava, thrown up to the height of from two hundred to four hundred feet, are visible in many sections of the country. An immense stream of this substance exists on the road from Albuquerque to the Pueblo of Zuñi and to Fort Defiance, about sixty miles from Albuquerque, ranging from a few hundred yards to a mile or more in width, and about forty miles in length. The centre of action is supposed, by a competent judge, to have been in the mountain of San Mateo, a high mountain, visible from Santa Fé and Albuquerque, and west of the latter city. This current seems to have flowed at a comparatively recent period—the undulations and curled waves being distinctly visible; and no mention is made of it by the Spaniards who first visited New Mexico, although they traversed the portion of country through which it has flowed. The Indians have no tradition of the eruption. The stream is not in the district inhabited by the Navajoes, but upon its borders. A few miles to the north and south of Fort Defiance large trap-dykes have been thrown up, running across the valley in which the garrison is situated. This, and the adjoining portions of this continent, everywhere give evidence of violent and relatively recent volcanic action. In addition to the eruptions found in so many sections of this particular portion of the continent, we have direct testimony in the account of the expeditions of the first Spanish adventurers to New Mexico and California, as in the following extract:

"They followed their route, [in the vicinity of the head of the Gulf of California,] and reached a place covered with ashes so hot that it was impossible to march over it, for they might as well have drowned themselves in the sea. The earth trembled like a drum, which caused the supposition of subterraneous lakes, and the ashes boiled in a manner truly infernal."

The soil is chiefly sand, mixed in some places with clay, and is very porous. It is little susceptible of cultivation—doubtless, in some measure, owing to the want of water for irrigation. The ground in many places, especially after having been wet, is covered with an efflorescence of impure carbonate of soda; and when such is the case, cultivation is out of the question. A qualitative analysis of the water used at Fort Defiance shows the presence of carbonates and sulphates of lime and magnesia and carbonate of soda, as the preponderating constituents; sulphate of soda, and traces of potash and chloride of sodium. The water is very "hard," and acts as a purgative upon those not accustomed to use it.

In wet weather, at the close of winter, and in July, August, and September, the country, from the porosity of the soil, is almost impassable, both in the valleys and upon the mesas, except by the beaten trails. The valleys and hills almost everywhere are covered with artemisia, and where it grows nothing else will flourish, not even grass, to any extent; and the appearance of the country, covered with this shrub, is one of exceeding desolation.

The district possessed by these people has had for many years the reputation of being the finest grazing country in the Territory of New Mexico, and the fame thereof has reached the eastern portion of the United States. The grass called in the country "sheep gama" is most abundant, and is found upon the sides of the mountains, upon the mesas, and in the valleys, when not too moist. What is denominated "horse gama" is a different species, and is not found except in limited quantities; almost none may, with propriety, be said to grow in the Navajo country. This variety of gama is excellent for grazing and for hay, being very nutritious and green in the winter, when deprived of its cuticle. Horses are exceedingly fond of this species, but of the "sheep gama" they are not. Taking the country at large, it will be found that, in regard to the abundance of natural pasturage, it has been vastly overrated, and we have no hesitation in saying that were the flocks and herds belonging to these Indians doubled, the country could not sustain them. There is required for grazing and procuring hay for the consumption of the animals at Fort Defiance, garrisoned by two companies, one partly mounted, fifty (50) square miles, and this is barely, if at all, sufficient. The hay procured is a very inferior article, and such as could not be sold at a price at all remunerative in the cultivated portions of the United States. The great reputation which this portion of New Mexico has obtained for grazing has, in part, no doubt, arisen from the fact of the country having been but little frequented by the Mexicans, and, consequently, but little known, and from the number of sheep driven from the settlements on the Rio Grande by these people, although this, without doubt, has been greatly exaggerated. It is far from uncommon that a country which is little known, has attributed to it many qualities which, on being more inquired into, have scarcely anything to rest upon other than the fertile imaginations of those who have passed through it, or live at some distance from it. The barrenness and desolation so inseparable from immense masses of rock, and hills and valleys covered with artemisia, are here seen and felt in their widest and fullest extent.

Pine, scrub-cedar, scrub-oak, and the piñon, are the more common trees. The mountains, except where composed of the bare rock, are sparsely covered with scrub-cedar, piñon, and stunted pines. The large pine, suitable for building purposes, is found in the recesses of the mountains, but is not abundant. The scrub-oak is scarce, and is suitable only as a last resort for economical purposes. A few small cotton-wood trees are occasionally seen in the damp ravines. A species of locust, bearing a very beautiful pink flower, has been found, but the trees are small and scarce. The wild hop grows in many places in great luxuriance, and is in every respect suitable for culinary purposes. A species of wild currant and wild gooseberry, and various kinds of willow, are met with. The variety of willow from which the "Northwestern Indians" procure the material so much used for smoking, is indigenous, and the bark, when prepared, is identical when smoked, in taste and smell, as we can say from our own experience, with that used by those Indians. It is said to be used by these Indians, but we have never seen them using it. They, however, do not use the pipe, but confine themselves to the cigarrito, made of the corn-husk.

The animals found in this country are the brown bear, black-tailed deer, antelope, wild-cat, porcupine, long and short-eared rabbit, prairie-dog, "coyote" and "lobo," two varieties of the wolf, and the common fox; two species of rattlesnake, and the tarantula are also found. The eagle, raven, turkey-buzzard, various kinds of ducks and teal, the "paisano," a species of jay, and what is called the magpie, the wild-turkey, white and sand-hill crane, woodpeckers and wrens, are the principal birds. We do not suppose this list to be complete.

The annexed table is an abstract from the meteorological register at Fort Defiance, in latitude 35° 40′, longitude 109° 14′ 30″, and at an altitude of about 8,000 feet above the sea, credit being due for the observations taken previous to October, 1854, to the medical officers stationed there before that time.

Mean temperature of four daily observations, and maximum and minimum temperature, and quantity of rain, in inches, for each month, at Fort Defiance, N. M.

	Sunrise.	9 A. M.	3 P. M.	9 P. M.	Mean.	Rain.	Remarks.
1853.							
October	29.61	46.64	59.83	40.77	44.70	.94	Max., 73° on 13th; min., 17° on 27th; range, 56°
November...	24.56	33.13	55.03	33.00	39.79	......	69° on 4th; 13° on 3d; 56°
December....	19.59	27.45	42.35	26.51	30.97	.25	57° on 2d; 6° on 19th; 51°
1854.							
January......	15.45	22.38	36.80	24.25	26.12	1.11	Max., 49° on 14th; min.—18° on 21st; range, 67°; thermometer stood at—20° at 5¼ a. m.
February	19.67	30.14	46.67	29.67	33.17	.09	Max., 54° on 5th; min., 2° on 15th; range, 52°
March	24.83	37.87	50.25	35.22	37.54	.45	59° on 30th; 8° on 13th; 51°
April.	30.20	50.33	60.10	44.46	45.05	.90	75° on 28th; 14° on 9th; 61°
May.........	35.83	54.93	64.83	48.64	50.38	.51	77° on 24th; 19° on 8th; 58°
June	45.46	68.33	77.23	58.60	61.34	1.24	92° on 22d; 30° on 2d; 62°
July	59.38	72.48	85.74	66.19	72.56	3.94	95° on 21st; 51° on 21st; 44°
August	54.83	67.77	75.51	61 74	65.17	5.24	84° on 7th; 46° on 25th; 38°
September...	46.13	59.33	70.40	52.60	58.26	3 47	79° on 6th; 35° on 15th; 44°
October	38.48	45.54	68.44	43.12	53.46	.62	76° on 3d; 25° on 30th: 51°
November...	26.90	34.43	56.73	34.29	41.81	.49	72° on 5th; 17° on 12th; 55°
December....	21.51	28.10	49.12	28.39	35.31	1.20	65° on 2d; 10° on 31st; 55°
1855.							
January......	12.67	20.70	43.93	21.60	28.74	.83	Max., 59° on 18th; min.—17° on 6th; range, 76°
February	22.22	30.06	51.14	31.07	36.68	1.72	61° on 28th; 13° on 1st; 48°
March	28.51	37.74	61.49	33.41	45.00	3.30	74° on 25th; 19° on 18th; 55°
April	32.93	42.03	69.26	36.03	51.06	.50	80° on 22d; 22° on 6th; 58°
May	35.60	47.55	73.38	40.10	54.44	.06	87° on 31st; 21° on 27th; 66°
June	50.76	62.03	86.45	56.04	68.61	.43	94° on 3d, 16th, 24th, and 27th; 34° on 9th; 60°
July	56.96	65.96	92.06	53.90	74.06	1.54	99° on 7th; 36° on 1st; 63°
August	52.64	59.09	79.24	48.19	65.90	3.92	91° on 2d; 43° on 22d; 48°
September...	49.10	60.43	73.10	54.40	61.09	2.86	81° on 15th; 39° on 30th; 42°
	7 A. M.	2 P. M.	9 P. M.		Mean.	Rain.	Hours of observations changed by the surgeon general of the army.
October	36.87	70.06	41.58	......	49.53	......	Max., 79° on 14th; min., 31° on 28th; range, 48°
November...	26.06	49.00	32.76	......	35.94	1.47	64° on 11th; 8° on 18th; 56°
December....	16.80	44.16	28.80	......	29.84	1.59	56° on 10th; 25° on 25th; 81°
1856.							
January......	11.67	40.06	19.35	......	23.67	.82	54° on 6th; —8° on 28th; 62°
February.....	13.31	42.03	19.68	......	25.00	1.54	51° on 9th; —3° on 8th; 54°

On the 25th of December, 1855, the thermometer at the hospital of Fort Defiance gave a reading of thirty-two (32°) degrees below zero at 6¼ a. m. The hospital is not by any means in the coldest portion of the garrison. Two hundred yards distant the mercury, in January, 1856, ranged from four to eight degrees below that at the hospital, and there is not the slightest doubt of the freezing of the mercury had the instrument been placed in the more exposed situation on the morning of December 25, 1855. A number of men on detached service had their hands and feet frozen, and some badly. The mercury was below zero four mornings in December, 1855, six mornings in January, 1856, three mornings in February, and on the mornings of the 1st and 2d of March it was also below zero.

The table above will give a fair idea of the climate of the country. The winter of 1855 and 1856 was more severe than any one known for many years. The wintry weather commenced on the 1st of November, 1855, and has continued up to the present time, (March 14, 1856.) The Rio Grande at Albuquerque was frozen over, and with ice sufficiently strong to bear a horse and carreta. Those Indians who live habitually to the north of Fort Defiance were obliged to abandon that portion of the country and move south with their flocks and herds in quest of grazing, on account of the depth of snow, which on the mountain, at whose base the fort is situated, was over two feet in depth in March, 1856. It is said by the Indians that once in many years a winter such as that of 1855 and 1856 is experienced, and the assertion is corroborated by the early Spaniards, but none of such severity has been felt since the occupation of the Territory by the United States troops. The winters in the portion of the country inhabited by the Navajoes are, however, generally of short duration and comparatively mild, there being occasionally experienced in December, weather in many respects similar to the "Indian summer" of the Eastern States. As the days become longer and the sun has more power, the roads become well nigh impassable, but it is almost fatal to leave them for the drier-looking but more treacherous ground, miring with horse or wagon being inevitable. In the spring, high winds, generally from the south and southwest, prevail, and clouds of dust fill the air, rendering travelling at that season disagreeable in the highest degree. Rain and snow also come for the most part from the south and west. In the summer the heat is not oppressive when one is not exposed to the direct rays of the sun; but, however warm the days may be, the nights are cool and pleasant, and blankets are comfortable throughout the summer. The greatest quantity of rain falls in July, August, and September. In April, May, and June, vegetation becomes much parched, suffering greatly oftentimes for water. The country is at such an altitude that evaporation goes on with great rapidity, and when showers are not frequent, vegetation suffers.

The amount of land fit for cultivation is very limited when compared with the extent of country. Out of New Mexico we doubt if any similar extent of country can be found in the domain of the United States, in which the proportion of cultivable land is so small as in the country inhabited by these Indians. It is generally necessary to irrigate for the production of crops, and it will be seen at once that the crops must be small when the great elevation of the country, from seven thousand (7,000) to nine thousand (9,000) feet above the level of the sea, and the limited supply of water, are taken into consideration. In some localities the Indians do without irrigation, by planting to the depth of ten and twelve inches, which can be done in some places without depriving the seed of air, on account of the porosity of the soil. Maize, pumpkins, beans, and wheat are the only productions. Wheat is not sown broadcast, but ten or fifteen seeds are planted in a "hill," after the manner of planting corn in the United States. Maize is planted in the same manner, the ground, in all cases, being prepared for planting by means of the hoe. The only fruit cultivated is the peach, and this is only found in the cañon of Chelly and a few small cañons adjoining. We have seen some fine specimens of this fruit brought from that cañon, but it can seldom be obtained ripe, as the only mode of transporting in vogue among these people is by means of buckskin bags on horses. During August and September hundreds of Indians are collected in the cañon just referred to, living on corn and peaches until the crops are exhausted.

Nothing can be learned of the origin of these people from themselves. At one time they say they came out of the ground; and at another, that they know nothing whatever of their origin; the latter, no doubt, being the truth. We have been informed by a Navajo, who is the most reliable man in the nation, that his tribe is very far from being pure blood; that his people are mixed blood with Utahs, Apaches, Moquis, and Mexicans, and to such an extent that it is a matter of no small difficulty to find a pure-blooded Navajo. On this account it is difficult to give a description that would apply to the whole tribe. Those of purest blood are of good size, nearly six feet in height, and well proportioned; cheek-bones high and prominent, nose straight and well shaped; hair long and black; eyes black; superciliary ridge small; teeth large, white, and regular, and frequently very handsome; maxillary bones not larger than usual in men of such stature; feet small; lips of moderate size; head of medium size and well shaped; forehead not small but retreating. Others, those generally of mixed blood, have low and very retreating foreheads; occiput largely developed; cheek-bones high and very prominent; maxillary bones large and projecting in front; nose and lips very much resembling those of the negro; about five feet two inches to five feet six inches in height; the *tout ensemble* giving the idea of a man far inferior to the Caucasian in the scale of existence, and approaching, in appearance, the brute creation, with which they have much in common.

So little government do these people possess, that it would be difficult to give it a name. Anarchy is the only form, if form it can be called. They have no hereditary chief—none by election; he who now holds the nominal title of chief was appointed by the superintendent of Indian affairs for the Territory, and the Indians had nothing to do with it; a silver medal and a cane is the insignia of office. The authority of the chief is merely nominal, and against the wishes of a number of his tribe he is powerless, and his authority melts away. Every one who has a few horses and sheep is a "head man," and must have his word in the councils. Even those who by superior cunning have obtained some influence, are extremely careful lest their conduct should not prove acceptable to their criticising inferiors. The "juntas," or councils, are generally composed of the richest men, each one a self-constituted member, but their decisions are of but little moment unless they meet the approbation of the mass of the people; and for this reason these councils are exceedingly careful not to run counter to the wishes of the poorer but more numerous class, being well aware of the difficulty, if not impossibility, of enforcing any act that would not command their approval. This want of a chief who would be looked up to by his people, and with power to carry out whatever measures are necessary for the welfare of his tribe, is a great drawback, and renders the management of these people a matter often of serious concern, and requiring always a great deal of tact, judgment, and discretion. The nation, as a nation, is fully imbued with the idea that it is all-powerful, which, no doubt, has arisen from the fact of its having been for years a terror and a dread to the inhabitants of New Mexico. The rich men, however, are fast becoming convinced that the government troops are not frightened at the mention of their names; yet this opinion is far from prevalent among those (and they are the great majority) who own no flocks or herds. Persons of this class frequently commit depredations to a small extent, and so powerless is the chief to prevent acts of this kind, or punish the depredator, that he frequently pays from his own herds the value of the article stolen. In short, their government is no government at all; the chief has no authority, and every one does that which seemeth good in his own sight. It is only the fear of the military power which keeps them in any kind of order.

Their houses are temporary huts of the most miserable construction. They are conical in shape, made of sticks, and covered with branches and dirt, from six to sixteen feet in diameter, and in many of them a man cannot stand erect. A hole covered with an old blanket or sheepskin serves the purpose of a door. The hovel is doubtless warm enough in winter, but must be sadly deficient in fresh air, at least to sensitive nostrils. Some live in caves in the rocks, and this can be the only foundation for the assertion that they "build stone houses." These people build no houses but the huts to which we have just alluded, and they show the high degree of civilization so much praised as being superior to that found among any other wild Indians in any portion of the territory of the United States. In the construction of their dwellings we have no hesitation in saying, that these people are greatly inferior to the "Northwestern Indians," as we have seen the habitations of both. When an Indian dies in one of these huts it is immediately abandoned, and upon no consideration can any one be induced to inhabit it again, or to use it for any purpose whatever. A small hut, about three feet in height, is erected for taking hot-air baths after any fatiguing exertion. A number of heated stones are placed inside, the person enters, and covering the hole with a blanket, is soon in a copious perspiration.

The men clothe themselves somewhat differently. Some wear short breeches of brownish-colored buckskin, or red baize, buttoned at the knee, and leggins of the same material. A small blanket, or a piece of red baize, with a hole in it, through which the head is thrust, extends a short distance below the small of the back, and covers the abdomen in front, the sides being partially sewed together; and a strip of red cloth attached to the blanket or baize, where it covers the shoulder, forms the sleeve, the whole serving the purpose of a coat. Over all is thrown a blanket, under and sometimes over which is worn a belt, to which are attached oval pieces of silver, plain or variously wrought. Many of the rich men wear, when "dressed," a coat and pantaloons brought from the United States. A shirt made of unbleached cotton cloth, also from the Eastern States, and breeches of the same material, made to come a little below the knee, are much worn by the "middle class." The men, as a rule, make their own clothes. These articles constitute the only covering, together with the breech-cloth and moccasins, that are used. Many are seen who wear nothing but a blanket, and some in summer, nothing but the breech-cloth, and we have seen some with no covering but moccasins and a cotton shirt, when the mercury was below zero. The moccasin is made of buckskin, with a sole of raw-hide, and comes well up on the leg. It is fashioned alike for men and women. The latter wear a blanket fastened about the waist, and sewed up the sides for a skirt. The front and back parts being attached over either shoulder, a covering is obtained for the front and back portions of the body. The skirt comes down below the knee, about half way to the ankle, the leg being well wrapped in uncolored buckskin. They sit upon their horses in the same manner as the men. As a general rule, neither sex wear any head-dress; an old cap or hat, or dirty rag, is sometimes worn, but they have no regular covering for the head, even in the coldest days in winter or warmest in summer. The hair is worn long, and tied up behind, by both men and women. That of sick persons is generally cut short, and that of children also, to enable the latter the more easily to get rid of the parasitic insects which are by no means uncommon to the whole tribe. With very few exceptions, the want of cleanliness is universal—a shirt being worn until it will no longer hang together, and it would be difficult to tell the original color. These people suffer much from rheumatism, and gonorrhœa and syphilis are not at all rare. Many have a cough, and look consumptive. Various herbs, sweating, scarifications, and incantations are the chief remedial measures. Women, when in parturition, stand upon their feet, holding to a rope suspended overhead, or upon the knees, the body being erect. Accouchment is generally easy, and of short duration; when difficult and prolonged, recourse is had to superstitious observances to bring about a successful issue.

The chief grain used for food is maize. When not fully matured it is pounded, mixed with pumpkins when these can be procured, wrapped in the husk, and baked in the ashes. They doubtless have other ways of preparing it, but we are not aware of them. It would be hard to say what they would not eat. The majority seem to live on what they can get—deer, antelope, sheep, horses, mules, rabbits, prairie-dogs; and we have seen some eat meat in such a state of putridity that the sight was disgusting in the extreme. All are very fond of bread and sugar, and seem to have a natural taste for all kinds of liquors. They never kill bears or rattlesnakes unless attacked, some superstition being connected with these animals.

The chief occupation of these people consists in rearing sheep and horses. The number of sheep has been very variously estimated, by those who have been much among them, the highest estimate being two hundred thousand, and this number is probably as near the truth as can be obtained. The wool is coarse and is never shorn. The sheep are in all respects similar to those raised by the Mexicans, occasionally one being seen having four horns. The males are permitted to run with the herds at all seasons, and the young, consequently, are born in the winter as well as in the spring and autumn, and many die. For this reason, their flocks do not increase with the rapidity generally believed by those not much acquainted with these people. It is a great mistake to suppose there is anything peculiar about Navajo sheep, for such is not the case. Goats are also reared, and are allowed to run with the sheep. The mutton is excellent in the autumn, when the sheep have had the benefit of the summer's grazing, but we think not at all superior to that obtained in the eastern and mountainous portions of the United States.

The spinning and weaving is done by the women, and by hand. The thread is made entirely by hand, and is coarse and uneven. The blanket is woven by a tedious and rude process, after the manner of the Pueblo indians, and is very coarse, thick, and heavy, with little nap, and cannot bear comparison with an American blanket for warmth and comfort. Many of them are woven so closely as to hold water; but this is of little advantage, for when worn during a rain they become saturated with water, and are then uncomfortably heavy. The colors are red, blue, black, and yellow; black and red being the most common. The red strands are obtained by unravelling red cloth, black by using the wool of black sheep, blue by dissolving indigo in fermented urine, and yellow is said to be by coloring with a particular flower. The colors are woven in bands and diamonds. We have never observed blankets with figures of a complicated pattern. Occasionally a blanket is seen which is quite handsome, and costs at the same time the extravagant price of forty or fifty dollars; these, however, are very scarce, and are generally made for a special purpose. The Indian's prefer an American blanket, as it is lighter and much warmer. The article manufactured by them is superior, because of its thickness, to that made in the United States, for placing between the bed and the ground when bivouacing, and this is the only use it can be put to in which its superiority is shown. The manner of weaving is peculiar, and is, no doubt, original with these people and the neighboring tribes; and, taken in connexion with the fact of some dilapidated buildings (not of Spanish structure) being found in different portions of the country, it has suggested the idea that they may once have been what are usually called "Pueblo Indians."

They possess from fifty thousand to sixty thousand horses, which are doubtless descended from those brought to this continent by the Spaniards. In rearing them attention is only given to the character of the sire; none being paid to that of the dam, as they suppose the superiority of the offspring to depend entirely upon the excellence of the former. The horses are small, a few handsome, and a very few fleet. They are frequently ridden fast and a long distance in a day; but they are usually often changed, and after having been ridden hard, are turned into the herd and not used again for many days. The saddle is not peculiar, but generally resembles that used by the Mexicans. They ride with a very "short stirrup," which is placed farther to the front than on a Mexican saddle. The bit of the bridle has a ring attached to it, through which the lower jaw is partly thrust, and a powerful pressure is exerted by this means when the reins are tightened. *Hanging down beneath the lips* are small pieces of steel attached to the bit, which jingle as they ride. The side and front parts generally consist of strings; sometimes made of leather, and not unfrequently ornamented with plates of pure silver, of the purity of which, by the way, these people are excellent judges. The chief merit of these horses consists in their being very sure-footed. It is not a little astonishing that the published accounts of them should be so far wide of the mark; such as "that they are equal to the finest horses of the United States, in appearance and value." We have seen great numbers of these horses, and instead of being "equal to the finest horses of the United States," we can say, without the slightest hesitation, that they have been vastly over-estimated, and are far inferior in appearance, usefulness, and value to the American horse. A few are comparatively fleet and handsome, but there are numbers of army horses in the Territory fleeter, better looking, and much more valuable. Two or three comparatively fine horses can occasionally be found in a herd of a hundred, but to give as a general character of these animals such as has been given in the above quotation is a great mistake. The usual price is thirty dollars.

It cannot, with truth, be said of these Indians that "they encourage industry by general consent," for the word "industry" cannot with propriety be applied to them. They plant wheat and maize, and rear horses and sheep, but are not, in any proper sense of the term, an industrious people. Like all Indians, they will not work more than is necessary for subsistence; and, were the word "laziness" substituted for "industry" in the quotation just given, the statement would be much more nearly correct. They are, however, industrious beggars.

They do not "make butter and cheese." These are rare articles in a Mexican household; and when we are aware that nearly all their knowledge of the arts of civilized life is derived from their intercourse with Mexicans, and that they have very few cattle, the error of attributing the manufacture of these articles to these people is apparent. Some who own cattle make from the curd of soured milk small masses, which some have called cheese; but to give this name and no description of the article, would certainly leave an erroneous impression. It bears little resemblance to the substance denominated cheese in the United States.

For ages these Indians have been a terror to the inhabitants of New Mexico. Wherever they have gone among the inhabitants of the valley of the Rio Grande, they have spread consternation and dismay;

doors have been closed and fastened, and invocations to the saints offered up for protection. They are even said to have insulted the governor in his palace, at Santa Fe, and filled the city with terror. Shepherds have abandoned their flocks at the appearance of one of these men of the mountains; and children have been, and are yet, frightened into good behavior by the mention of their name. But since the occupation of the country by the United States forces, this prestige is fast melting away even with the Mexicans. Their great fame for bravery has arisen not so much from any courageous disposition superior to that of other Indians in the Territory, as from their numbers and from the character of the people with whom they have had to deal.

Some years since, a small party of Delawares appeared among them to revenge an outrage perpetrated upon one of their number who had wandered west of the Rio Grande, and to this day these people hold a Delaware in the highest respect. Prior to the abolition of Spanish authority upon this continent, the Spaniards spread desolation throughout their entire country and compelled them to beg fervently for peace. But this wholesome state of things changed for the worse when the Spanish rule ceased, and until the authority of the United States was established in the Territory, the Navajoes ran riot, masters wherever they went; and, from the fact of their having been allowed so to do, they yet hold themselves in high esteem; but instead of being feared by government troops, the order of things is fast becoming reversed, as may be perceived from the fact of two companies of United States troops having held in check over two thousand warriors mounted and armed.

They use the bow and arrow, and spear, and use them well. The bow is about four feet in length, and made of some kind of wood which is said not to grow in the Navajo country, and is covered on the back with a kind of fibrous tissue. The arrow is about two feet long and pointed with iron. The spear is eight or ten feet in length, including the point, which is about eighteen inches long, and also made of iron. In case of war, they would give no inconsiderable trouble; not so much from active fighting, as from frequenting high and almost inaccessible cliffs, in which the country abounds, and the many hiding-places in the cañons and recesses of the mountains, which, for a time, from their superior knowledge of the country, they would, in a measure, be able to do. It would not be correct, however, to suppose that they would not fight, for so great an idea do they have of their prowess, that they no doubt would trust in their skill and bravery until it was apparent that these would not avail; but, like all Indians, they would not risk a fight, if it were possible to avoid it, unless they possessed greatly the advantage in position and numbers. Some of them have fire-arms in addition to their usual weapons. We have seen some excellent looking rifles in the possession of some of them, bearing the name of "Albright," (of St. Louis, doubtless,) which the owners state were procured in the Territory of Utah. They have not been sufficiently accustomed to the use of these weapons to use them skilfully, and at present are much more formidable with the bow and arrow. They value fire-arms highly, and obtain them whenever an occasion offers.

Of their religion little or nothing is known, as, indeed, all inquiries tend to show that they have none; and even have not, we are informed, any word to express the idea of a Supreme Being. We have not been able to learn that any observances of a religious character exist among them; and the general impression of those who have had means of knowing them is, that, in this respect, they are steeped in the deepest degradation. Their system of morality is exceedingly defective. No confidence can be placed in any assertion they may make, unless it be manifestly for their welfare to tell the truth; they give utterance to whatever they suppose is calculated to promote their interests. Theft and mendacity are common vices. The habit of stealing is so common, that they will appropriate to themselves whatever they can lay their hands on, whether of any use or not, such as door-knobs and keys. Not only do they steal from those who do not belong to their tribe, but continually from one another. Those who possess anything which they consider valuable, invariably hide it from their own family; for husbands cannot trust their own wives. So little confidence do they place in each other, that those who own herds fear to leave them, lest some depredation be committed by their own people. Application has been made to the present commanding officer of Fort Defiance, (Major Kendrick, U. S. Army,) by one of the richest men in the nation, to have his cattle placed under the protection of the guard which has charge of those belonging to the post, on the ground that he could not prevent people of his own tribe from killing them. And we may add, in this connexion, that the same person requested the commandant to put balls and chains on some of his peons (a system of peonage existing among these people) who had been caught stealing, not daring to take the responsibility of punishing the culprits upon himself.

Such facts as these show how ill-founded is the statement made of these people, that "dishonesty is held in check by suitable regulations." If any such regulations exist, (which we do not hesitate to doubt,) they are most emphatically a dead letter. Their morals are extremely loose—the husband keeping a constant watch upon his wife, lest she stray from the paths of rectitude; and venereal diseases are by no means uncommon. The women, however, exert a great deal of influence—more than in the majority of Indian tribes. They have entire charge of the children, and do not allow the father to correct his own offspring. In fact, an Indian has said that he was afraid to correct his own boy, lest the child should wait for a convenient opportunity, and shoot him with an arrow. The husband has no control over the property of his wife, their herds being kept separate and distinct; from which, doubtless, arises the influence of the women not only in their own peculiar sphere, but also in national matters, which it is well known they oftentimes exert. The wife is usually bought with horses, of her father—no ceremony that we are aware of being performed; and if upon trial she does not like her husband, she leaves him, and there the matter ends. Polygamy is practised by all who can afford to sustain more than one wife; but the women do not necessarily inhabit the same hut, or even live in the same neighborhood. Property does not descend from father to son, but goes to the nephew of the decedent, or, in default of a nephew, to the niece; so that the father may be rich, and upon his death his children become beggars; but if, while living, he distributes his property to his children, that disposition is recognised.

Captives taken in their forays are usually treated kindly. Those who have been some years among them, for the most part prefer remaining rather than join their own kindred. Those who do leave them are generally such as doubtless have been punished for their own misdeeds, and are such, judging from what we have seen, as would be a nuisance to any community, however savage—surpassingly idle, lazy, and vicious.

Hospitality exists among these Indians to a great extent, all being said to share whatever food they may have with any one who visits them. Nor are these people cruel, in the usual acceptation of the word as applied to barbarous nations. They are treacherous; they will steal, and will not hesitate to kill, when by so doing their purposes are more easily accomplished; but they are not prone to murder for the mere love of taking life.

They have frequent gatherings for dancing, and are fond of games of skill, and of chance—the latter being more in vogue than the former, as they are greatly addicted to gambling, often risking everything upon the issue of a single game. One game is played somewhat on the principle of gambling with dice. Their singing is but a succession of grunts, and is anything but agreeable.

In speaking of these people we have been compelled to differ in many respects from what has been written concerning their manners and customs, and mode of life. A character has been given them (Transactions of the American Ethnological Society, vol. 2) that would do honor to a civilized and christianized community for industry, morals, and intelligence. We hazard nothing in the assertion that they are neither an industrious, moral, nor a civilized people. In the whole nation one or two may be found who are reliable men, considering they are Navajo Indians, who would not falsify merely for the sake of falsifying, or steal for the love of stealing; but we would not advise any one to place confidence in even the best of these people, lest he should find himself leaning on a reed easily broken.

The lack of traditions is a source of surprise. They have no knowledge of their origin, or of the history of the tribe. If they are a branch of the race of people who attained such a high degree of civilization in Mexico, they have greatly degenerated, and would scarcely be recognised by their more polished brethren. Upon this head all is involved in obscurity and doubt, though there is no want of fanciful speculation. Resemblances have been found, where, upon more careful inquiry, it is impossible to find the faintest trace; old dilapidated buildings, evidently of Spanish origin, have been searched throughout their length, breadth, and height, for vestiges of a by-gone race. Pieces of broken pottery have been closely scrutinized, wisely pondered over, and carefully figured in books as relics of a past age and a civilized people; samples of which, in no way different, may at any time be obtained by breaking a "tinaja," which can be procured from any pueblo for half a dollar. The ardent and laudable desire shown to trace the origin, divisions, and resting-places of this people, have, we think, taken a wrong direction, and that their language alone can be of service in tracing them, if they can be traced at all. It is impossible to learn anything from the people themselves, as they have no traditions. A volume of no mean size might be written, were all the stories of interpreters taken for truth; but it would be found one mass of contradictions, and of no value whatever. If ever these people possessed the art of making pottery they have lost it, for they certainly make none now. They cultivate no cotton, neither do they produce any fabrics of that material, nor do they make any feather-work. Though we have had an abundant opportunity, we have never seen anything approaching, in the slightest degree, the description of the feather-work of the ancient inhabitants of Mexico. Almost all the arts they possess, and which are very few, may be accounted for by the occupation of New Mexico by the Spaniards. With minds filled with one absorbing idea—that of discovering the stopping-places of the renowned race found by the conquerors in the valley of Tenochtitlan—this country has been hurriedly traversed, and old buildings have been restored in drawings by enthusiastic imaginations, and filled with the ancestors of these people. A unity of origin of different races has been deduced from manners and customs that are common to humanity.

We have ventured to suggest, that the language must be studied to discover a common origin, if such ever existed. To trace it in their habits, or in their arts and customs, or by catechising Indians, is, we think, entirely out of the question. It is a matter of no great difficulty to learn from intelligent Pueblo Indians that one day they expect to see Montezuma; that they worship him, and keep fires constantly burning to await his coming. Indians are proverbially shrewd in these things, and unless questions are put with extraordinary tact, they are keen enough to see what answers would be well received, and answer accordingly. As well might the origin of the tribes in New Mexico, because some of them keep a constant fire, (upon which so much stress is placed,) be ascribed to the inhabitants of ancient Persia or of Rome, as to any other. It has been no uncommon custom among nations in different periods of the world's history to kindle sacred fires; so that we think little reliance can be placed upon this coincidence; and we believe just as little can be placed in the statements of the comings and goings and miraculous interpositions of Montezuma. The so-called hieroglyphics are equally unsatisfactory. Many of the pictures (which are very rude) were evidently drawn for mere pastime, and with reference to past, present, or future events, have no significance whatever. The figures drawn upon pottery are only the result of a rude taste common to uncultivated people. Those sketched upon rocks are of a similar character; some, however, seem to have been engraven for the purpose of giving a visible embodiment to the lecherous imaginings of an uncivilized people, whose inclinations in many respects would be disgraceful to the brute creation. These remarks, however, apply more especially to the Pueblo Indians in the vicinity of the Navajo country, the Navajoes themselves having, as we have remarked, no traditions, make no pottery, nor do they keep any sacred fires burning.

A new country and a new people are apt to excite the imagination of those who see them for the first time. Especially is this the case in the present instance. This country, which was long a *terra incognita*, has been pointed out as the probable temporary abode of the celebrated people found by the Spaniards in the valley of Mexico, while everything relating to them is interesting on account of the obscurity which envelopes their origin.

NOTE.—It affords me much pleasure to acknowledge my obligations to Major Kendrick, of the army, for information in reference to this country and these people; and especially as the value of his information is equalled only by his willingness and his kindness in imparting it.

CORRESPONDENCE.

TOPOGRAPHY OF BLACK MOUNTAIN.

By Hon. THOMAS L. CLINGMAN, of N. C.

The following communication contains information relative to the topography of a portion of our country but little known. The highest point of the Black Mountain, now called Clingman's Peak, is the most elevated spot on our continent, east of the Rocky Mountains. This fact has been fully established, since the date of Mr. Clingman's letter, by a series of measurements, conducted with every precaution to insure accuracy, by Professor Guyot. He found the altitude of Mount Mitchell to be 6,585 feet, and that of Clingman's Peak to be 6,710 feet.

J. H., *Secretary S. I.*

Asheville, N. C., *October* 20, 1855.

My Dear Sir: The interest you manifested, a year or two since, with reference to one of the mountains in our region, induces me to address this letter to you. From time to time there have been discussions as to where the highest point of land is to be found east of the Mississippi river. You doubtless recollect a controversy as to the relative height of the White Mountains of New Hampshire, and the Black Mountains of North Carolina. Professor Mitchell succeeded, I think, in making it appear that that portion of the Black Mountain since called Mitchell's Peak, or Mount Mitchell, was higher than Mount Washington, the elevated point of the White Mountain range.

But even at the time of his measurement I was of the opinion that he had not succeeded in getting upon the highest point of the Black Mountain. In our frequent conversations, both before and since that time, he did not appear to feel at all confident on the subject. It is with reference to the fact that another peak of the mountain is higher than any ascended, or measured by him, that I purpose now to speak. It may appear strange to some persons, at a distance, that at this time there should be any doubt as to the fact, capable seemingly of so easy demonstration. Those who have been on the mountain, and who therefore know the difficulty, heretofore, of getting to the top, do not share in this feeling. When, some twenty years ago, Dr. Mitchell began his observations with reference to the height of the mountain, it was much more inaccessible than it has since become, by reason of the progress of the settlements around its base; so that he was liable to be misled, and thwarted by unforeseen obstacles in his efforts to reach particular points of the chain; and when he did attain some part of the top of the ridge, nature was too much exhausted to allow more than an observation as to the immediate locality. It has happened that in his several attempts, both from the north and the south, he never succeeded in reaching the highest portion of the range.

The Black Mountain lies wholly on the western side of the Blue Ridge, the name given in this State to the mountains which divide the waters of the Atlantic from those of the Mississippi. It is nearly twenty miles in length, and in form almost makes a semi-circle, with one of its ends projected in the direction of its tangent. In a part of its course it approaches within three miles of the Blue Ridge, and is connected with that mountain by a lower ridge than itself. At the junction there rises a pyramidal peak, known as the High Pinnacle of the Blue Ridge, and which is probably the very highest point of the "Great Divide," surpassing, I think, both the Grandfather and the Hog-back. About one mile north of where this connecting ridge unites with the Black, stands Mount Mitchell. Something more than one-third of the entire chain of the mountain runs from this peak, first in a westerly, and at length in a northwesterly direction. Rather more than half of the ridge of the Black, therefore, lies to the northeast of Mount Mitchel. The chain in its entire length is covered, not only on its top, but down its sides, for one or two miles, with dense forests of the balsam-fir tree. Its dark green foliage gives the mountain, whether seen in summer or winter, from all points of the compass, and at all distances, the appearance of ground recently burnt over, and irresistibly suggested the name by which it has been known since the earliest settlement of the country. That point which I am satisfied is the highest of the range, is situated about three (3) miles to the northeast of Mount Mitchell. Having lately visited it, with a view of determining, as nearly as possible, under the circumstances, its altitude, I now propose to give you the results of my observations. I shall, in the first place, assume that the height of Mitchell's Peak has been correctly ascertained, though, in common with several subsequent observers, I am inclined to think that Dr. Mitchell rather understates its real altitude above the sea. During his observations he had a barometer stationed at Asheville, for the purpose of comparison with that which he carried with him. Asheville he estimated to be twenty-two hundred (2,200) feet above the level of the ocean. He gave for the height of the peak bearing his name six thousand six hundred and seventy-two (6,672) feet. Between this and another point my comparison has been so made as to leave no doubt whatever of the superiority of the latter. During the period of my observations, one barometer was observed by Mr. W. McDowell, the clerk in the Bank of Cape Fear, at Asheville, and another by Dr. A. M. Forster, who lives a mile from the village, and who was kind enough to assist me in this manner. From this place to the top of Mount Mitchell the distance is not more than twenty miles in a direct line. The barometer which I carried with me has been in my possession some months; and repeated trials at various elevations, of well-known heights, have given me the fullest confidence in its accuracy. Whenever there is a difference of ten feet in the height of two stations, no difficulty is experienced in determining it. On the 8th

September last, at nine o'clock and twenty-four minutes, at the top of Mount Mitchell, the barometer stood twenty-three and forty-nine hundredths (23.49) inches. At the highest point, which I reached precisely at twelve o'clock, or two hours and thirty-six minutes later, it was twenty-three and three-tenths (23.3) inches. I remained on the top until one o'clock without perceiving any change. Taking each of these nineteen hundredths (.19) at this altitude to represent eleven feet, there would be a difference of two hundred and nine (209) feet in favor of the latter peak. At Asheville, from eight o'clock to twelve o'clock, (the time when he closed the bank,) Mr. McDowell saw no change whatever in his barometer. Dr. Forster observed his at ten o'clock, at twelve o'clock, and at two o'clock, without any change whatever being perceptible. Neither observed his barometer at a later hour than I have indicated above. I found, however, at six o'clock in the evening, on my return to the house I had left at eight o'clock in the morning, there had, in the interval of ten hours, been a fall of ten hundredths, (.1). Independently of the fact that neither gentleman saw any change, during the morning, in his barometer, I have reason to believe that the fall took place in the afternoon, because it became somewhat cloudy, and from the circumstance that the barometer continued to fall slowly for two or three hours later in the evening. If, however, part of this fall should be taken to have occurred during the morning, between the hours of nine and twelve o'clock, it would somewhat reduce the altitude of the highest peak above Mount Mitchell, but would still show it to be the higher from one hundred and forty (140) to two hundred (200) feet. Of the fact of its greater elevation no one will doubt who visits them both on the same day, provided it be clear enough to allow them to be seen in connexion with the other mountains around.

Until, however, I had attained the highest point, I did not feel altogether sure but that one of the other peaks immediately north of it, might not be equally or nearly as high. It happens, however, that the course of the ridge northward was directly towards the Roan, a mountain that for nine miles of its length has nearly a uniform height, ascertained by Dr. Mitchell to be six thousand one hundred and eighty-seven (6,187) feet above the sea, or more than five hundred (500) feet lower than the Black. As its direction is nearly at right angles with the line from my position to it, portions of it were beyond the highest points of the northern range of the Black. Thus, though it was distant nearly thirty (30) miles, in a direct line, and though it was more than five hundred (500) feet lower than the spot on which I stood, yet portions of it were visible directly over these points. Having been there more than once, I saw clearly that the line of vision passing the top of any one of the peaks on the Black would have struck it below the crest of its ridge. What was still more satisfactory to me, was the fact that these three points of the Black appeared to the eye to have about the same elevation, being almost, but not quite, in a line with each other. The northern, or most remote one, at the termination of the mountain, near Burnsville, was ascertained by Professor Mitchell to be ninety (90) feet lower than the Roan. It was distant from me about eight (8) miles, and though much lower than

I was, yet it appeared as high as the nearer points; making it clear, therefore, that the descending line from my eye to it, did not fall below any part of the chain north of me. I was in this way fully satisfied that the ground on which I stood was higher than any of these points.

I may remark, in confirmation of the barometrical measurement, that, when one is standing on the top of Mount Mitchell, while the peak I visited appears the highest of all above the horizon, the remote ones are still visible, and may be seen still in connection with the Roan, but appear to rise considerably above it. Taking the indications of the barometer to be correct, as observed by me, and assuming the height of Mitchell Peak to be six thousand six hundred and seventy-two (6,672) feet, the other would be six thousand eight hundred and eighty-one (6,881) feet above the ocean. But, according to the surveys for the line of the extension of the Western railroad, as detailed in the report of Major Gwynn to the legislature of our State, in December last, and which were brought within one mile and a quarter of Asheville, the height of this place—I mean the square where the court-house stands—is two thousand two hundred and sixty (2,260) feet above tide-water. This survey corresponds in its results with one made many years ago by the Charleston and Cincinnati Railroad Company. Sixty (60) feet should, therefore, be added to Dr. Mitchell's estimate of the height of this place, which would give his peak an elevation of six thousand seven hundred and thirty-two (6,732) feet, and the higher one, that of six thousand nine hundred and forty-one (6,941) feet. For the reasons already stated, the height of the latter may be subject to some deduction, but not to an extent to affect materially this estimate. My object, however, is not so much to prove its absolute height as to show that it excelled any point as yet measured, and leave to the more competent the task of determining the precise altitude. There is no doubt whatever but that it is the highest portion of the Black Mountain, and that point of land east of the Rocky Mountains having the greatest altitude above the sea. As it has never, to my knowledge, been designated by any particular name, a description of its position is necessary to identify it. If one should travel along the top of the ridge from Mount Mitchell, in a northerly direction, less than a half mile will bring him to Mount Gibbes, so called from the fact that it was measured by Professor Gibbes, of Charleston, South Carolina, a few years since. I have been informed that he estimated it as being four (4) feet higher than Mitchell's Peak. If there be a difference in the elevation of the two points, it probably does not exceed that stated by him. From this place there is an irregular descent for about one (1) mile, where my companions and I found ourselves nearly five hundred (500) feet below the top of Mount Mitchell. We then had to climb a handsome, regularly-shaped pinnacle, which reminds one of a sugar-loaf, and which rises to within one hundred and fifty (150) feet of the height of Mitchell's Peak. On its north side the descent is less. Our way then continued over irregular elevations and depressions for about two (2) miles, till we found ourselves in a sort of prairie ground, or natural meadow, magnificent and beautiful in the extreme. From the further edge of it, a steep but regular ascent of about two hundred and twenty (220) feet brought us to the highest point. The top is level for eight (8) or ten (10) yards, and on it the balsam-fir tree still retains its place, though shortened to the height of only twenty (20) feet. On the right hand there runs off, in the direction of Toe river, a ridge which slowly descends to that, stream, distant some six (6) or seven (7) miles. It is thus easy to identify this peak, and its approach is no longer difficult.

From the head of the Swannonoah, at Mr. Steps', where an angler can find speckled trout, there is an easy way to the Mountain House, built by Mr. William Patton, of Charleston, South Carolina. Its present occupant will provide one with pleasant lodgings, and, what mountain journeys render so welcome, all such comforts "for the inner man" as this region affords, with fresh salmon from Scotland, and champagne from France, to make them go down easily. After resting here awhile, at the height of five thousand four hundred and sixty (5,460) feet above the sea-level, two miles of travel on horseback, as hundreds of ladies can testify, will bring you to the top of Mount Mitchell.

When one is upon this peak, he appears to be on a centre, from which there run off five immense mountain chains. To the northward stretches the main ledge of the Black, with a succession of cones and spires along its dark crest. On its right, from the far northeast, from the Keystone State, across the entire breadth of Virginia, seemingly from an immeasurable distance, comes the long line of the Blue Ridge or Alleghany; but when it passes almost under him, it is comparatively so much depressed as scarcely to be perceptible, save where at the point of junction, stimulated by the presence of its gigantic neighbor, it shoots up into a pinnacle so steep, that, to use a hunter's phrase, it would "make a buzzard's head swim, if he were to attempt to fly over it." Thence it runs southerly, till it touches South Carolina, when it turns to the west, and is soon hidden behind collossal masses that obstruct further vision in that direction. As the chain of the Black sweeps around westwardly, it is suddenly parted into two immense branches, which run off in opposite courses. The northern terminates in a majestic pile, with a crown-like summit, and numerous spurs from its base; while to the south there leads off the long ridge of Craggy, with its myriads of gorgeous flowers, its naked slopes and fantastic peaks, over which dominates its great dome, challenging, in its altitude, ambitious comparison with the Black itself.

Let the observer then lift his eye to a remote distance, and take a circuit in the opposite direction. Looking to the southeast and to the east, he sees, beyond King's Mountain, and others less known to fame, the plain of the two Carolinas stretched out over a field of illimitable space, in color and outline indistinguishable from the "azure brow" of the calm ocean. Nearer to him, to the northeast, over the Linville Mountain, stands squarely upright the Table Rock, with its perpendicular faces; and its twin brother, the "Hawk-bill," with its curved beak of over-hanging rock, and neck inclined, as if in the act to stoop down on the plain below. Further on there rises in solitary grandeur the rocky throne of the abrupt and wild Grandfather. This "ancient of days" was long deemed the "monarch of mountains," but now, like other royal exiles, he only retains a shadow of his former authority in a patriarchal name, given because of the grey beard he shows when a frozen cloud has iced his rhododendrons. Westward of him stands a victorious rival, the gently undulating prairie of the Roan, stretching out for many a mile in length, until its green and flowery carpet is terminated by a castellated crag—the Bluff.

From this extends southerly the long but broken line of the Unaka, through the passes of which, far away over the entire valley of East Tennessee, is seen in the distance the blue outline of the Cumberland Mountains, as they penetrate the State of the "dark and bloody ground." In contrast with the bold aspect and rugged chasms of the Unaka, stands the stately figure of the Bald Mountain, its smoothly shaven and regularly-rounded top bringing to mind some classic cupola; for when the sunlight sleeps upon its convex head, it seems a temple more worthy of all the gods than that Pantheon, its famed Roman rival. As the eye again sweeps onward, it is arrested by the massive pile of the great Smoky Mountain, darkened by its fir-trees, and often by the cloudy drapery it wears. From thence there stretches quite through Haywood and Henderson to South Carolina's border, the long range of the Balsam Mountain, its pointed steeples over-topping the Cold Mountain and Pisgah, and attaining probably their greatest elevation towards the head of the French Broad river.

Besides these the eye rests on many a "ripe green valley" with its winding streams, and on many a nameless peak, like pyramid or tower, and many a waving ridge, imitating in its curling shapes the billows of the ocean when most lashed by the tempest. And if one is favored by Jove, he may perchance hear the sharp, shrill scream of his "cloud-cleaving minister," and, as he sweeps by with that bright eye which "pierces downward, onward, or above, with a pervading vision," or encircles him in wide curves, shows reflected back from the golden brown of his long wings,

> "The westering beams aslant"

of the descending sun.

But from Mount Mitchell, where one is still tempted to linger, since my first visit, a way has been opened quite to the highest point. As one rides along the undulating crest of the ridge, he has presented to him a succession of varied, picturesque, and beautiful views. Sometimes he passes through open spots smooth and green enough to be the dancing grounds of the fairies, and anon he plunges into dense forests of balsam, over ground covered by thick beds of moss, so soft and elastic that a wearied man reposes on it as he would on a couch of softest down. In the last and largest of the little prairies, one will be apt to pause awhile, not only for the sake of the magnificent panorama in the distance, but also because attracted by the gentle beauty of the spot, its grassy, waving surface, interspersed with flattened rocky seats, studded, in the sun-light, with glittering scales of mica, and here and there clusters of young balsams flourishing in their freshest and richest green, in this, their favorite climate, pointed at top, but spreading below evenly till their lower branches touch the earth, and presenting the outlines of regular cones.

From this place the highest peak is soon attained. Any one who doubts its altitude may thus easily satisfy himself, for it stands, and will continue to stand, courting measurement. One who from the eminence looks down on its vast proportions, its broad base, and long spurs running out for miles in all directions, and gazes in silent wonder on its dark plumage of countless firs, will feel no fear that its "shadow will ever become less," or that in the present geological age it will meet the fate fancied by the poet, when he wrote the words—

> "Winds under ground, or waters forcing way,
> Sidelong had pushed a mountain from his seat,
> Half sunk with all his pines."

I fear, my dear sir, that I have made this letter much too long for your patience; and yet the vegetation and surrounding scenery of this mountain, peculiar and remarkable as it is, might well tempt me to say many things that I have omitted. I hope your interest in all that relates to natural science will find an apology for my having so long trespassed on your valuable time.

I am very truly yours, &c.,

T. L. CLINGMAN

Prof. JOSEPH HENRY.

CORRESPONDENCE.

COMMUNICATION RELATIVE TO THE PUBLICATION OF SPANISH WORKS ON NEW MEXICO.

DEAR SIR: We ask leave to call your attention to the existence of some MSS. of a very early date, which belong to the history of this country, with the hope that you may consider their publication as a proper object for the Smithsonian Institution to undertake, and in the Spanish—the language in which they are written.

It is known to the Secretary that an invasion by the Spaniards of the territory since called New Mexico, took place in the years 1540, 1541, and 1542, accounts of which have come to us from two hands—Castañeda and Iarramillo. They are together long, and possess a variety of interest.

The army marched through the present States of Cinaloa and Sonora, crossed the Gila river, and having passed through the celebrated towns of Cibola and crossed the Rio Grande near Santa Fé, came upon the Buffalo Plains, and are supposed to have reached the Mississippi river. They give us the first reliable information of the curious state of Indian civilization existing there; people living in communities, of diverse languages, inoffensive, industrious, gaining their support principally by husbandry, and practising all the virtues with a rigor that belonged to no other American nation, and we believe everywhere without a parallel.

A copy of these MSS. is in the Historical Collection of James Lenox, Esq. They have never been printed in the Spanish, and only in the French; but, from some careful comparisons of other translations that have come from the same source with the original works, we are satisfied that they cannot be relied on for accuracy; yet these have afforded nearly all that is quoted or known in this country of the discovery and early history of New Mexico. The publication of these papers in the language in which they are written will give opportunities for their being rendered into other languages; still, however exact may be a translation, it must always be important, in writings of such authority as these, to have the original to refer to in matters of nicety and doubt.

At the same time that the viceroy of New Spain directed an army to the north by land, he sent forward another by sea up the Gulf of California to co-operate with Coronado. Alarcón disembarked at the mouth of the river Gila, and ascended the Colorado river in boats; but finding the famed cities not so near the South sea as they were supposed to be, the forces did not form a junction. The account of this expedition appeared in the Italian, and from it an English translation afterwards in Hackluyt. The original has never been printed. A copy is now in this country in the hands of John R. Bartlett, esq.

On the return of Alarcón, one of his "cosmographers," Domingo del Castillo, drew a small map of the country they had traversed, and generally of the geography of the north, as it was understood at that time. It portrays with wonderful accuracy the lands of recent discovery, the seacoast, the position of the Spanish settlements, and the course of the rivers. It is on a single quarto page, and there is a copy of it in this country.

Thus we have here many important documents giving accounts of these early explorations, and it is believed they may be got together at the present time. They have been greatly needed in the country for a number of years past, and their publication would prove of utility and of great public interest.

From a particular calculation that has been made, it is found that the foregoing narratives would cover about 323 pages of the folio of the volume of the Smithsonian publications.

There is a second series of documents appertaining to a later period of the history of New Mexico, Texas, and adjoining territories, that are even less known than the first, to which we also ask the Secretary's particular attention.

1. Memoirs respecting the *Provincias Internas* of New Spain, by Lieutenant José Cortes, of the royal engineers, written in the year 1799. They will occupy 120 pages.

2. Diary & Route through the country newly discovered to the N.N.W. of New Mexico, of the Fathers Silvestre Velez de Escalante and Francisco Atanacio Dominguez, in the year 1776. This will cover 116 pages.

These, in manuscript, are in the library of Peter Force, esq.

3. Report of Lieutenant Cristobal Martin Bernal and Father Eusebio Fr. Kino, and others, in the year 1697, on the State of Pimeria. It will occupy 31 pages.

4. Letter from Father Kino, touching an expedition made with the Cap. Carrasco, in 1698, from Pimeria to the N.W. and Gulf of California and back, a journey of 300 leagues. It will fill five pages.

5. Letter of the same, dated 16th September, 1698, respecting the condition of Pimeria and the recent conversions therein. It will cover five pages.

6. Letter of the Father Silvestre Velez de Escalante, dated 2d April, 1778, giving a history of New Mexico, by order of his superior, from the archives in Santa Fé—pp. 25.

Of these documents—3, 4, 5, 6—Buckingham Smith, esq., has copies from those in the royal archives in the city of Mexico.

7 and 8. Diary of Friar Francisco Garces to the river Colorado in the year 1775, and Diary of Father Pedro Font, at the same time, to San Francisco, with a small map by him. About 200 pages.

9. Diary of Ensign Juan Mateo Monge to the N. in a journey with Father Kino in the year 1697. Supposed to be about 75 pages.

Both these documents are in the Department of Foreign Affairs in the city of Mexico, where copies of them can be procured with facility.

We are, sir, very respectfully, your obedient servants,

EDWARD ROBINSON,
Prest. Am. Ethnological Society.
HERMANN E. LUDEWIG,
Sec'y Am. Ethnol. Society.
E. GEO. SQUIER.
HEN. C. MURPHEY.
WM. B. HODGSON, *of Georgia.*

Prof. Joseph Henry,
Secretary of the Smithsonian Institution.

Sunnyside, *August* 26, 1854.

From a perusal of the accompanying letter, drawn up, as I understand, by Buckingham Smith, esq., late Secretary of Legation in Mexico, I am induced to believe that the documents therein specified are well worthy of publication, both in their original language and in translation, by the Smithsonian Institution.

WASHINGTON IRVING.

Lynn, *September* 7, 1854.

I concur in the opinion expressed by Mr. Irving, especially in regard to the first series of documents mentioned in Mr. Smith's letter.

WM. H. PRESCOTT.

Cambridge, *September* 13, 1854.

The Spanish documents enumerated in the communication drawn up by Buckingham Smith, esq., appear to me valuable, as furnishing new and interesting materials for a history of portions of the United States hitherto little known, and I believe the Smithsonian Institution would confer an important benefit on the country by publishing them.

JARED SPARKS.

New York, *October* 5, 1854.

I shall be very glad to see the documents referred to by Messrs. Irving, Prescott, and Sparks, made accessible through the press. The Diary of Father Pedro Font seems to be not the least inviting of the series. Give us light, all the light that history can shed, on the vast territory we have annexed.

GEORGE BANCROFT.

New York, *October* 11, 1854.

The publication of the documents referred to in Mr. Smith's letter is very desirable.

Those named in the first series (and especially Castañeda's account) are very valuable.

FRANCIS L. HAWKS.

REPORT

OF

RECENT PROGRESS IN PHYSICS.

BY DR. JOH. MULLER,

PROFESSOR OF PHYSICS AND TECHNOLOGY IN THE UNIVERSITY OF FREIBURG.

[Translated from the German for the Smithsonian Institution.]

It is a part of the original plan of organization of the Institution to furnish occasional reports on the progress of special branches of knowledge, and in accordance with this the following report has been translated from the German, in which it was written.

It relates to a branch of science which, perhaps, more than any other, is in the process of practical application to economical purposes, and is principally composed of materials not accessible to the English reader. The original article is by Professor Müller, the celebrated German physicist. The translation was made by the late Woods Baker, Esq., of the Coast Survey, whose untimely death, science has been called to mourn.

We are indebted to Vieveg & Son for the wood-cuts, who have liberally furnished us with copies of the original at the cost merely of the metal and the casting.

A second portion of the work will be published in the appendix to the next annual report of the Regents, and so on until the whole is completed. The present portion will be found particularly valuable in relation to the construction and use of galvanic batteries.

The report pre-supposes such a preliminary knowledge of the subject as may be obtained from the elementary books used in our schools; and in order to render some of the passages of the text more easily understood, a few notes have been added at the end. The rapidity with which government work is printed does not allow the additions or corrections to be inserted on the proper page, and hence in studying the article the notes should be examined first to ascertain the part of the text to which they belong.

GALVANISM.

SECTION FIRST.

THE CHEMICAL AND CONTACT THEORIES.

Introduction.—[The author commences his report on the recent progress of galvanism with a brief account of the discussions which have been carried on relative to the two hypotheses, as to the origin or cause of the development of the electricity in the galvanic apparatus, viz: whether it is due to the contact of the metals or to the chemical action of the acid on one of them. But it must be evident to those who have paid attention to the history of this branch of science that justice cannot be done to this interesting discussion in a few pages of this report, and that the author has merely given a brief sketch of only one of the hypotheses; but since this is comparatively little known, except in Germany, it will be acceptable to the English reader.]

This discussion has been carried on with no little warmth; but the history of science shows that when a theory is properly established, controversy in reference to it ceases. If any one, at this time, should assert that the earth does not revolve about the sun, astronomers would give themselves little trouble to refute the objection which might be urged against the received theory. Drieberg recently attacked the physical theory of the pressure of the air, but his opinions have not produced the least excitement among physicists. Opposition provokes discussion only when theories have not risen above mere hypothesis, and this is partly the case with reference to the source of the electricity of the galvanic circuit.

The matter in dispute is not fully ripe for decision, and we can only expect a perfect solution of the difficulty when we are better informed of the nature of electricity itself. In Euler's time the theory of the vibrations of light was advocated with much ability, yet this distinguished mathematician was unable to render it generally acceptable, and it was only by the discovery of new facts, particularly those of polarization, that the theory received that form which silenced opposition. The explanation of the origin of the electricity of the pile must rest on the theory of the molecular constitution of matter in relation to the ethereal medium, the existence of which we are obliged to admit in order to generalize the facts of light, heat, and other emanations from the sun. The establishment of a general theory of this kind which will give definite conceptions of the relation of known phenomena, and lead us to infer the existence of facts of which we have as yet no idea, is one of the most important objects of science, and even the attempts which have been made to arrive at a general view of this kind have been fruitful in new and interesting results.

The materials, however, for the full establishment of such a theory do not at present exist, and consequently we cannot expect more than approximations to a generalization of the character required.

§ 1. *Brief sketch of the theories.*—Volta found that when a slip of zinc and one of copper were soldered end to end, the one exhibited signs of plus, and the other of negative electricity. He therefore concluded that the electricity was due to the contact of the two metals, and that the acid of the circuit only performed the office of a conductor. This view was at first generally adopted, but as the phenomena came to be more minutely studied, it was found insufficient to explain them, and Wollaston, Davy, and others, adopted the hypothesis that the electricity was due to the chemical action of the acid on one of the metals. It has been shown that a galvanic current can be produced by the action of two liquids without metallic contact, and therefore the theory of contact requires to be so modified as to extend the idea of contact to that of the liquids as well as the solids of the galvanic combination. On the other hand, it has never been fully proved that the contact of two metals does not in itself produce a disturbance of the electrical equilibrium, though this effect does not appear sufficient to account for the great amount of electricity evolved in the action of the battery. The two theories, properly modified, approximate each other, and each, perhaps, involves elements of truth.

The hypothesis, that the development of electricity is only the consequence of chemical action—that without chemical decomposition of the electrolyte no electricity can appear in the circuit, is that against which the attacks of the advocates of the contact theory were directed; and it is, indeed, opposed to a great number of facts. The chemical theory, in this form, ignores completely the fundamental experiment of Volta; it does not explain how the tension of electricity of the open pile increases with the number of plates. But what is most inconsistent with the maintenance of this theory, is the circumstance that a number of galvanic circuits can be constructed in which, when open, not a trace of chemical decomposition takes place, but which, nevertheless, give rise to currents when they are closed.

Schönbein, in a memoir "*On the cause of the hydro-electric current*," in his "*Beitragen zur Physicalischen Chemie*—(*Basel*, 1844,") has referred to several such circuits. A solution of perfectly neutral sulphate of zinc does not attack zinc; yet a combination of zinc and copper in this solution produces a current.

Another weighty objection to the form of the chemical theory, which attributes the formation of the current to a preceding chemical attack upon one of the metals of the circuit, is, that the electromotive force of a circuit is not at all proportional to the violence of the attack. If the copper of a Daniells' battery be placed in a solution of sulphate of copper, the electro-motive force of the apparatus is almost wholly unchanged, whether the zinc is placed in water, dilute sulphuric acid, or in a neutral solution of sulphate of zinc. This has been proved by Svanberg, among others, by accurate measurements. (*Pogg. Ann.*, *LXXIII*, 290.) If the current had its origin in chemical action, the electro-motive force should be far greater upon application of dilute acid than of water and sulphate of zinc.

It is a fact, that the current of the water-battery (hydro-kette) cannot circulate without decomposition of the liquid. The decomposition appears essentially connected with the passage of the electricity through the liquid, and the contact theory has fully acknowledged the important part which chemical decomposition in the cells plays in the formation of the current. A dispute as to whether decomposition is the cause of the electrical current, or whether the chemical decomposition in the battery is preceded by a state of electric tension, the source of which we need not at present ask, is the same as though there should be a controversy as to whether the motion of a water-wheel is owing to the fall of water or the weight of water. The weight occasions the fall, and the fall the revolution of the wheel, just as the electric tension occasions chemical decomposition, in consequence of which the current circulates. Even Faraday, who is prominent in maintaining chemical decomposition as the source of the electrical current, concedes that decomposition is preceded by a state of tension of the liquid; for he says, in the case where he applies his theory of induction to electrolytic decomposition:

"The theory assumes that the particles of the dielectric (now an electrolyte) are, in the first instance, brought, by ordinary inductive action, into a polarized state, and raised to a certain degree of tension or intensity before discharge commences; the inductive state being, in fact, a *necessary preliminary* to discharge. By taking advantage of these circumstances, which bear upon the point, it is not difficult to increase the tension indicative of this state of induction, and so make the state itself more evident. Thus, if distilled water be employed, and a long, narrow portion of it placed between the electrodes of a powerful voltaic battery, we have at once indications of the intensity which can be sustained at these electrodes, * * * for sparks may be obtained, gold leaves diverged, and Leyden bottles charged."—*Twelfth Series of Experimental Researches on Electricity*, 1345.

Thus Faraday himself concedes that a polarized state precedes decomposition of the electrolyte in the separate cells of the battery, consequently it precedes the formation of the current. The difference between Faraday's theory of the pile, and the contact theory, is not to be found in the fact of deriving the circulation of the current from chemical decomposition in the cells. The contact theory supposes, with Faraday, that in the water-battery (hydro-kette) the formation of the current is the consequence of chemical decomposition in the cells. It also supposes, with Faraday, that this decomposition must be preceded by a state of tension; and it is only in reference to the cause of this tension, which is nothing else than the electro-motive force, that there can be any difference of opinion.

§ 2. *Schönbein's chemical theory.*—Schönbein has attempted so to modify the propositions of the two theories as to bring them more in harmony. The following are the principal features of his theory, extracted from his own paper:

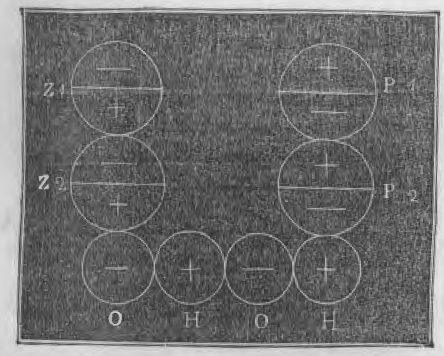
"Whatever may be the cause or force by which elementary substances are enabled to unite together into an apparently homogeneous body, and to continue in their new combination, this much is certain—that a change must always take place in their condition if a third element is brought into contact with one of the substances, which exercises a perceptible chemical attractive force upon the other components of the compound. To illustrate our idea, let us select water as an example. Oxygen and hydrogen are held together in this compound with a given force; or, to express the same thing in other words, the chemical attractive forces of the elements of water are in a state of equilibrium. An oxidable substance, as zinc, being now brought into contact with water, it will have a chemical attraction of a certain intensity for the oxygen of the water. But in consequence of this attraction, the chemical relation which subsisted between the oxygen and hydrogen before the presence of the zinc must be changed, or the state of the original chemical equilibrium of these elements is modified in a certain degree or destroyed; or, in other words, under the circumstances mentioned, the oxygen in each particle of water will be attracted in two opposite directions—towards the zinc in contact with the molecule of water, and also towards the particle of hydrogen contained in this molecule.

"Now, since the least mechanical molecular change taking place in a body disturbs its electrical equilibrium, or its particles become electrically polarized, the above described change, caused by the zinc in the original chemical affinity of the oxygen for the hydrogen of the water, is followed by the electrical polarization of the substances in contact with each other. The particle of zinc nearest the water becomes positive; the oxygen side of the molecule of water touching the zinc is negatively polarized; the hydrogen side of the same particle, positively. It is self-evident that the particle of water in contact with the zinc will exert an inductive action on its adjoining molecules, the latter upon the next particles, and so on, until all the molecules of water connected together are in the state of electrical opposition or polarization. Since an inductive action traverses the particles of water from the place where the zinc and water are in immediate contact, all the contiguous particles of zinc become polarized, and in such a manner that the side of each particle turned from the water indicates negative polarity, and the side towards the water positive polarity. By placing in this polarized water a good conductor or a substance easily electrified, which is indifferent towards the oxygen of the water, such as platinum, the sides of the particles of this substance in immediate contact with the water become negatively electrified, and the sides of the same particles turned away from the water positively in consequence of an inductive action, which is exerted by the polarized water upon the platinum.

"All the other particles of the platinum are similarly affected, that is, the side of each molecule turned from the water has positive polarity; that of each towards the water has negative.

"The following diagram gives a clear representation of the electrical condition in which the particles of zinc, water, and platinum are found:

Fig. 1.



"It is very evident that this condition of all the particles of the substance in question will last as long as the cause producing the polarization exists; that is, as long as the chemical attraction of the zinc for the oxygen of the water continues. But if the contact of the zinc and water be broken, the opposite electrical conditions in which the hydrogen and oxygen of each molecule of water exist are neutralized, which is necessarily followed by a like change in the particles of platinum.

"Now, by placing the particle Z^1 of the arrangement in contact with P^1, the negative side of the former will be in connexion with the positive side of the latter, and the opposite states of the two particles will mutually neutralize each other. But at the same moment in which the equilibrium takes place in these particles, it takes place between each two contiguous particles throughout the whole circuit; consequently between the positive side of a particle of zinc in contact with the water and the negative oxygen particle of a molecule of water in contact with the zinc. Likewise the electro-negative state of a particle of platinum is in equilibrium with the positive state of the oxygen particle of the water molecule with which it is in contact.

"The electrical equilibrium which now takes place between each metallic particle and each component of a molecule of water is not possible without a decomposition of the latter, and this very act of equilibrium must be considered as the true and ultimate cause of the electrical decomposition of water."

* * * * * * * *

"Evidently, according to this view, the actual combination of the oxygen with the zinc of the battery is regarded as only a secondary action of the current or the act of electrical equilibrium, and not as the cause or source of the current itself. The chemical combination of the molecules of oxygen and zinc being completed, and a substance being in the water which can remove the oxide of zinc from its place of formation, a new particle of zinc will come in contact with a molecule of water, and the latter, with all the particles of oxygen lying between the zinc and platinum, will be electrically polarized anew. By keeping the circuit closed, a neutralization of the electrical opposition will take place between each two contiguous particles of the voltaic battery, and the decomposition of new molecules of water follows; and thus proceeds polarizing and depolarizing, circulation and electrolysis, until the necessary conditions cease to be fulfilled.

"Suppose now that water is placed between two metals which manifest an exactly equal attraction for oxygen; it is evident that it will be drawn with equal force, under these circumstances, in opposite directions: hence the effects upon the particles of water by the metals must be mutually destroyed; the components of these molecules will not be polarized; and in closing such a circuit, neither circulation nor electrolytic action can take place.

But if the water be placed between two metals, one of which has greater affinity for oxygen than the other, the chemical equilibrium existing between the components of each molecule of water will be destroyed, and in proportion to the difference of oxidability of the metals used.

Since the destruction of the chemical equilibrium between the components of the particles of water also involves the destruction of electrical equilibrium, and the latter is as much more considerable as the former is greater, it follows, that the degree of electrical polarization of the molecules of water between metals must be proportional to the difference of oxidability of the said metals; or, to express the same thing differently: the magnitude of the electrical tension which the parts of an open circuit have for each other, is measured by the magnitude of the difference which exists between the degrees of oxidability of the metals composing the circuit." * * *

"Now, if the oxidability of a metal is actually related to its voltaic action as stated, it is very evident that the place which a metallic body has in the tension series of the contactists denotes the degree which belongs to the same metal in the scale of oxidability of metallic bodies. Comparing the tension series of the metals obtained by water and the galvanoscope, with the scale of oxidability of the same bodies determined by ordinary chemical methods, it is impossible not to see the great accordance between the two series." * * *

"Now, since we have a number of electrolytes in which other metaloids than oxygen, such as the haloids, sulphur, and seleneum, play the part of anions in their combination with hydrogen, it follows from what has been said, that the electrical tension series of metals determined with different electrolytes, cannot accord with each other perfectly. This want of accordance has been placed beyond doubt by various experiments, and the number of cases is not very small in which the same two metals manifest a different voltaic relation for each other when they are placed in different electrolytic liquids; so that the same metal which in one liquid is positive towards the second metal, manifests the opposite in another liquid.

"The case of a reversal of voltaic action which the same two metals exhibit in two different liquids must, in accordance with the above statements, always appear when the chemical relation of these metals to the anions of the electrolytes used is not the same; that is, when the affinity of one and the same metal for the two anions of the electrolyte does not exceed the affinity of the other metal for the same anions, or shows the opposite relations."

"Experience above all teaches that in general the proportions of affinity which exist between the metals and oxygen are similar to those which take place between those bodies and the haloids, sulphur, seleneum, &c.; hence the voltaic relations which the metals manifest in electrolytic liquids not containing oxygen, accord so frequently with those which are observed in the same bodies in water." * * *

"Let us now consider those batteries which consist of one metal and two electrolytic liquids.

"The most interesting example is that composed of water, muriatic acid, and gold.

"This battery yields a current which passes from the gold to the acid, and from this to the water. This current is very weak, and by reason of the rapid positive polarization of the gold immersed in the water, it soon ceases to have a measurable strength.

"The origin of this current depends upon the simple fact, that the gold possesses a greater chemical affinity for the chlorine of the muriatic acid, than for the oxygen of the water." * * * *

"It is easily inferred from the preceding explanation, that all voltaic arrangements consisting of two different electrolytes and a metal must form circuits, in case the metal used has a greater chemical affinity for the anion of one of the electrolytic bodies than for the anion of the other. It is likewise evident that the force of the current thus produced must be proportional to the difference of the two affinities." * * * * * * * * * *

"It need hardly be mentioned, that other than metallic bodies can also be placed at either end of a continuous series of electrolytic molecules to polarize them. According to the chemical relation which such bodies manifest for the anion or kation of an electrolyte, its molecules will be polarized in the latter or the former direction.

"If, for instance, chlorine be brought in contact with one of the ends of a series of particles of water, the chemical equilibrium of this molecule will be destroyed, and its hydrogen side will be directed towards the chlorine. If the end of a platinum wire be placed in contact with chlorine, and the other end of the same wire with any particle of water of the same series, a current must arise, passing from this end of the platinum wire through the water to the chlorine, while the latter combines chemically with the hydrogen of the water.

"On the contrary, a non-metallic substance being placed at the end of a continuous series of molecules of water, having a chemical attraction for the anion of this series, polarization of the particles of water will occur, and it will be opposite to that which chlorine occasions in the case mentioned above.

"Such a substance, for instance, is sulphurous acid, which tends to unite with the oxygen of the water. This tendency is sufficient to polarize the particles of water, and under favorable circumstances to set the current in motion.

"By placing at one end of a series of molecules of water, a body which has a chemical affinity for the anions, and at the other end a substance having affinity for the kations of the molecules, it is evident that this series will be under a double polarizing influence, and the electro-motive forces coming into play will mutually increase each other. A series of such electrolytic molecules, having, for instance, chlorine at one of its ends and sulphurous acid at the other, if closed by a conductor forming a voltaic circuit, must generate a current stronger than that which appears in the cases where chlorine alone or sulphurous acid alone are used, other things being the same.

"It is hardly necessary to remark, that my hydrogen and platinum battery, as well as Grove's new gas pile, are voltaic arrangements, which, although presenting some peculiarities, belong to the class of combinations described above."

Schönbein finally describes the so called *hyper-oxide battery*. By immersing in water a clean platinum plate, and one furnished with a covering of hyper-oxide of lead, a current will arise as soon as the two metal plates are put in metallic connexion; and the positive current will pass from the clean platinum plate, through the liquid to the other covered with the hyper-oxide of lead.

The formation of the current, as well as its direction, is easily explained.

It is well known that half of the oxygen in the hyper-oxide exhibits a great tendency to separate and combine with oxidable bodies. Schönbein has, moreover, shown that this second portion of oxygen in the same hyper-oxide has a greater affinity for oxidable substances than even uncombined or free oxygen; hence the hyper-oxide will polarize the particles of water in such a manner that the hydrogen sides turn towards the hyper-oxide.

Other hyper-oxides act in like manner.

§ 3. *Comparison of the Contact theory with that of Schönbein.*—If we compare Schönbein's theory with the contact theory, we must understand that they both run parallel, that the phenomena of the open and closed battery can be explained equally well by both; for Schönbein only removes the place of excitation of electricity from the point of contact of the metals to the point of contact between metal and liquid. But Schönbein's theory has a decided advantage in this—that it can determine beforehand in all voltaic combinations, the direction of the current from the chemical relations of the substance forming the battery, while the contact theory is wanting in such a principle.

That the same metals give a current first in one direction, and then in another, according as one or another liquid is placed between them, is perfectly explicable according to the modified contact theory, from the different electromotive relations of the liquids to the metals. Schönbein's theory not only allows the possibility of a reversal of the current by changing the liquids, but it also tells us in what cases, and why, the currrent is reversed.

Thus Schönbein's theory always determines *a priori* from the chemical nature of the substances which form the battery, the directions of the current, no matter whether the battery is formed of two metals and a liquid, or of two liquids and a metal; while, on the contrary, the contact theory in many cases is so much at fault that it is unable to determine beforehand the direction of the current from a general principle, and in such cases (*e. g.* in batteries of water, muriatic acid and gold; water, sulphurous acid and platinum,) an experiment is required to find the direction of the current.

From these considerations, one would suppose that there could be no doubt as to which of the two theories should prevail; whether Schönbein's chemical theory, or the modified contact theory. Yet I cannot decide unconditionally for Schönbein's theory, because it entirely ignores a well established fact, the *fundamental experiment* of Volta, and is unable to give an explanation of it.

That electricity is generated by different metals coming in contact with each other, is a fact well established by experiments, purposely instituted in various forms, and which cannot be ignored nor set aside by such interpretations of the experiments as the opponents of the contact theory have contrived.

The name *contact electricity* is exceedingly unfit, and may have contributed not a little to the confusion of the discussion in question; properly speaking, all electricity, wherever and however it may appear, is contact electricity; for, in generating electricity, two different kinds of bodies are necessarily, under all circumstances, brought into contact. In electrical machines, glass and amalgam; in the voltaic pile, two metals and a liquid; in the thermo pile, different metallic rods. Wherever heterogeneous substances are brought into contact, a development of electricity takes place, but generally a state of electrical equilibrium soon ensue. For a continuous excitation of electricity this state of equilibrium must be continuously destroyed; this is done in frictional electricity, by removing the contact of the closely-touching places of the heterogeneous substances; in the hydro battery, by the decomposition of the electrolytes; in the thermo pile, the circulation of electrical equilibrium is produced by the disturbance of thermal equilibrium.

SECTION SECOND.

DETERMINATION OF THE CONSTANT VOLTAIC BATTERY.

§ 4. *Unit of force of current.*—Every conductor of electricity, however good, opposes some resistance to its propagation, and many researches have been made to determine the laws of the transfer through conducting media. The following facts have been established by experiment:

1. Galvanic electricity tends to diffuse itself through the whole capacity of a conductor, and consequently the resistance to conduction will be in proportion inversely to the transverse section of a conductor.
2. All parts of a closed circuit, including the battery itself, are traversed at the same time by the same quantity of electricity, whatever be the diversity of their nature.

It follows from the second law, that the absolute intensity of the electricity that passes in a closed circuit depends upon two circumstances: first, on the force which develops the electricity, and which is called the electro-motive force; and second, on the resistance to conduction presented by the whole circuit taken together. Ohm was the first to give a precise statement of these laws, and to deduce with mathematical precision, from them, consequences which have become of great importance in establishing the theory of the battery as well as in the application of electricity to the arts.

If we designate by S the value of the current, or its power to produce effects, and by E the electro-motive force of a single element, whether this be due to contact chemical action, or both, and by R the resistance in the battery, then the relations may be expressed by the equation

$$S=\frac{E}{R}$$

In the foregoing equation we have supposed that the battery consists of a single element, and that the metals are joined by so short and thick a conductor that it offers no appreciable resistance. If, however, the battery consist of n number of elements, joined as before, then the electro-motive power will be n times greater, and also the resistance will be increased in the same ratio, and therefore we shall have

$$S=\frac{n\,E}{n\,R}$$

If, now, we introduce an additional resistance in the conductor which joins the poles, and represent this by r, then the expression becomes

$$S = \frac{n\,E}{n\,R + r}$$

This is the fundamental equation of Ohm, from which all the relations of galvanic combinations can be derived.

When currents of different forces or strengths are to be compared, there must be, first of all, a common measure. Hitherto, to my knowledge, there have been *three* different units proposed, each of which we shall consider somewhat in detail.

Pouillet proposed (Pog. Ann., xlii) as a unit of force of the galvanic current that which a thermo-electric element of copper and bismuth would produce, when so closed that the whole resistance is equal to a copper wire of 20 metres long and 1 millimetre thick; one soldering being maintained at a temperature of 100°, the other at 0°.

Jacobi (Pog. Ann., xlviii 26) compared the deflection of a Nerwander tangent-compass with the decomposition of water produced simultaneously by the current; thus reducing the indications of the tangent-compass to the chemical effect. For unit of force he assumed the current which generates in one minute, one cubic centimetre of explosive gas at the temperature of 0°, and height of the barometer at 760 millimetres.

Weber took for his unit the current which, circulating at a distance around the unit of surface, produced the same action as the unit of free magnetism.

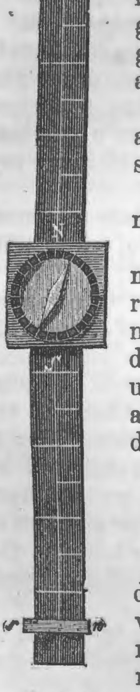
To explain what Weber means by the unit of free magnetism we must dilate somewhat.

A magnetic bar *s n* placed north or south of a magnetic needle, and perpendicular to the magnetic meridian, as represented in Fig. 4, will tend to deflect the needle from the magnetic meridian, while the terrestrial magnetism tends to draw it back. The magnitude of the deflection depends upon the relation of the two forces; the tangent of the angle of deflection is the quotient of the force of the bar divided by the

$$\frac{f}{T} = \text{tang}\, v, \qquad (1)$$

denoting by v the angle of deflection, by f the force with which the bar attracts the needle from the magnetic meridian, and by T the force with which the terrestrial magnetism tends to draw it back.

Fig. 4.



But the action of the bar upon the needle is proportional to the third power of its distance from the needle, so long as this distance is moderately great in comparison with the dimensions of the bar and the needle. Denoting the distance by r, the product fr^3 must be a constant quantity, which we will denote by M.

But this product fr^3, or M, indicates the moment of revolution which the rod would exert upon the needle when placed at the distance (1) from it, and its effect beyond this approximation should always increase in the same proportion in which the cube of the distance decreases. But this relation between action and distance does not hold good for short distances; this, however, does not prevent the use of the moment of resolution fr^3 or M reduced to the unit as a measure of the magnetism of the rod.

Multiplying equation (1) by r^3, and placing $fr^3 = M$, we get

$$\frac{M}{T} = r^3. \text{ tang. } v.$$

or

$$M = T\, r^3 \text{ tang. } v. \qquad (2)$$

Assuming the deflecting bar and the needle to be equally magnetic, let the magnetism in both be so developed that the reduced moment of revolution M is equal to the pressure which the weight of a milligramme would produce on a lever-arm of one millimetre, if, instead of the force of gravity, this weight be acted upon by a force under whose influence double the space traversed in the first second is equal to the unit of length, (*one millimetre,*) *then this would be the unit of free magnetism.*

With this unit the terrestrial magnetic force is also to be measured, or, in other words, T is to be expressed in terms of this unit. The manner in which the value of T is determined, adopting that just defined as the absolute measure, may be found in Weber's original treatise on this subject, and in an elementary account of it in my Treatise on Physics, (3d edition, 2d vol., p. 48.)

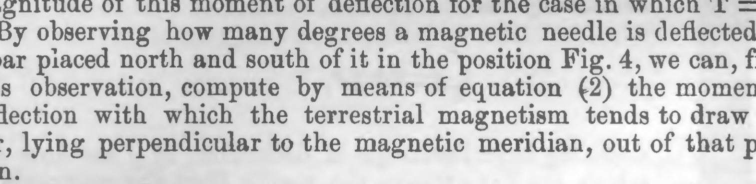
If the value of T is determined according to the absolute measure, then equation (2) gives the reduced moment of revolution of a magnetic bar expressed in the same unit.

But the quantity M has still another meaning than the one already mentioned, namely, $C = T\,M$ is the moment of revolution with which the terrestrial magnetism tends to draw the bar, placed perpendicular to the magnetic meridian, out of this position. (Treatise on Physics, 3d edition, 2d vol., p. 44.) Thus, M denotes the magnitude of this moment of deflection for the case in which $T = 1$.

By observing how many degrees a magnetic needle is deflected by a bar placed north and south of it in the position Fig. 4, we can, from this observation, compute by means of equation (2) the moment of deflection with which the terrestrial magnetism tends to draw the bar, lying perpendicular to the magnetic meridian, out of that position.

By placing the magnet east or west of the needle, as indicated in Fig. 5, the former, at the same distance, deflects the needle more,

Fig. 5.



and so that the tangent of the angle of deflection w is exactly double the tangent of deflection v, which the same magnet, at the same distance, would have produced in the position Fig. 4; hence, under circumstances otherwise the same, we have—

$$\text{tang. } v = \frac{\text{tang. } w}{2}$$

By making the experiment, not in the position Fig. 4, but that of Fig. 5, we get—

$$M = \frac{T\, r^3 \text{ tang. } w}{2},$$

The relation of the circulating current, which traverses the ring of the tangent compass, in the magnetic meridian, to the terrestrial magnetism, as well as to the magnetic needle, may now be compared with the effect of the magnetic bar placed in the position of Fig. 5.

If the circulating current of the tangent compass deflects the needle w degrees, we have—

$$\text{tang. } w = \frac{2\,\pi\, g}{r\, T}$$

denoting by g the force of the current, and by r the radius of the ring: thus we have for the reduced moment G of the deflection of the circular current, which corresponds to the moment of deflection M of a magnetic bar

$$G = \frac{T\, r^3 \text{ tang. } w}{2.} = \pi\, r^2\, g. \qquad (3.)$$

This G is the force with which, under the relation stated above, the circular current would be deflected from the plane of the magnetic meridian, if the force of the terrestrial magnetism were = 1.

Making $\pi\, r^2 = 1$, we will have $G = g$;

hence g is the moment of a circular current which circulates in unit of surface.

From equation (3) we get for g the value—

$$g = \frac{T\, r \text{ tang. } w}{2\,\pi}. \qquad (4)$$

thus we obtain a value for the force of the current g, measured by the moment of deflection of a current traversing around the unit of surface, expressed in absolute measure, by substituting for T its absolute value.

§ 5. *Comparison of the different current units.*—Theoretically these three units of force are determined with perfect exactness, and if the matter were considered only in a scientific point of view, each of them would seem acceptable, though the preference would be due to Weber's unit.

But the selection must be different when practical wants are also considered.

The galvanic battery enters so multifariously into a process of art, that it is of great importance to have methods by which the constants of a galvanic arrangement can be determined with accuracy. Unfortunately, such methods hitherto have been but little known, and thus it is that we have descriptions of the useful effect of many different combinations of galvanic apparatus, but none such as give an accurate comparison of different apparatus, and a consequence is that we are frequently deceived in their value.

For determining the constants of a battery, it is essential to understand, in the first place, with reference to the unit of current, whether the observations made for that purpose are comparable with other observations at different places with different instruments. To render such a unit popular, it should be accessible to practical men, who though acquainted with the principles of electricity, are unable to enter into the specialities of the science; hence it is fit to select such a unit only whose definition is easily and generally comprehensible; moreover, the unit should be such, that the determination of the force of the current for obtaining it may be accomplished with the least possible apparatus.

Considered in this light, the unit first brought into use by Jacobi has by far the preference. I will endeavor to justify this opinion.

§ 6. *Reduction of Pouillet's unit to chemical measure.*—To compare the indications of any compass with Pouillet's unit, we must have a thermo-electrical element exactly equal to that used by him; and for that purpose it is necessary that the entire resistance of the circuit, including the wire of the compass or multiplier, should be equal to the resistance of a copper wire 20 metres long and 1 millimetre thick. But the current which such a thermo-electrical element produces under the indicated conditions is exceedingly feeble, or at least much weaker than the current of hydro-electric batteries, which yield a practical useful effect; and in instruments with which ordinarily the force of the current of hydro-electric batteries is measured, as tangent compasses, sine compasses or Mohr's torsion galvanometer, Pouillet's unit will produce but a very small deflection. This unit produces, for example, in Weber's tangent compass, having a ring 40 centimetres in diameter, a deflection of from 5 to 7 minutes; in Mohr's torsion galvanometer, a deflection of about 1½ degree; thus it is requisite to have very small subdivisions of a degree in these instruments with accuracy, for determining this angle of deflection with sufficient exactness to make the angle itself, or its tangent, the unit in measuring strong currents.

Since the instruments do not admit of sufficiently accurate reading of such small angles, an indirect method must be introduced. The following, perhaps, is the simplest for this purpose:

Pass the current of the thermo-electrical element, serving as unit, through a multiplier, and observe the deflection produced: suppose it is 16°, the entire resistance here is equal to the resistance of a copper wire 20 metres long and 1 millimetre in diameter.

Now pass the current of a hydro-electric element through the same multiplier, but insert, in the form of platinum or German-silver wire, resistance until the deflection is as great as that produced by the thermo-electrical element, or until it amounts, as before, to 16°.

The whole resistance which the hydro-electrical current has now to overcome must be determined and reduced to that of copper wire. Suppose it is equal to the resistance of a wire 1 millimetre in diameter and 22,000 metres long.

By making the entire resistance less by the removal of wire, the current will become stronger in equal measure. Make the resistance, for instance, 200 times less, so that the entire resistance to be overcome by the current of the hydro-electrical element is equal to the resistance of a normal copper wire only 110 metres long; the current will now be 200 times stronger than that which produced a deflection of 16° in the multiplier. This current will produce a considerable deflection in each instrument adapted to measuring stronger currents, as a Weber tangent compass; let it be 19°.

Thus a current which indicates in the tangent compass an angle of deflection of 19°, of which the tangent is = 0.344, is 200 times as strong as the unit of the current, thus we have for the tangent of the angle to which the unit corresponds—

$$\frac{0.344}{200} = 0.00172.$$

By this result all the indications of the tangent compass can be easily reduced to Pouillet's unit.

Pouillet used, not a tangent compass, but a compass of sines, in all his researches on this subject.

To decompose one gramme of water in one minute, the current passed through the water must have a force = 13,787 of Pouillet's unit. Each gramme of water yields 1862.4 cubic centimetres of detonating gas (at 0° and a pressure of 760 metres); hence to obtain one cubic centimetre of detonating gas per minute, a force of current of $\frac{18787}{1862.4}$ = 7.4 Pouillet's unit is necessary.

The above examples will suffice to show that the reduction of the data of a rheometer for stronger currents to Pouillet's unit can be obtained only by a whole series of operations by no means simple. First, the resistance of the thermo-electric element, and of the multiplier, must be determined, and so much resistance must be added that the sum of the resistances shall have the value given above; then the resistance of the conductor of the hydro-electrical element must be found, and after inserting as much resistance in its circuit, the quantity of this resistance is to be determined; then the entire resistance must be reduced to an aliquot part, and the corresponding deflection of a rheometer used for stronger currents observed, &c. The end here is attained only through a circuitous process, and errors of observation are unavoidable in each operation, which affect the final result; the complexity of the process also has a prejudicial influence on the accuracy of the determination.

The above comparison of Pouillet's unit with the chemical effect produced, gives us the means of easily converting the data of a rheometer into this unit; we have only to pass the current simultaneously through the rheometer and an apparatus for decomposing water, to determine how much detonating gas will be evolved while the rheometer indicates a certain number of degrees. Since each cubic centimetre of detonating gas corresponds to 7.4 of Pouillet's unit, it is known also how many of Pouillet's unit correspond to the observed deflection of the rheometer. Pouillet's unit has been used here only nominally; the deflection of the rheometer alone has, in fact, been compared with the chemical effect, and there is no reason why this comparison should not be adhered to.

§7. *Reduction of Weber's unit to the chemical measure.*—The definition of Weber's *absolute measure of the force of a current* is by no means so simple as to encourage the hope of making this unit easily very generally comprehended. This inconvenience, however, might be disregarded, if the determination of the force of the current were easily derived from this absolute measure.

If a Weber's tangent compass (which should not be less than 40 centimetres in diameter) be used in getting the angle of deflection which a current produces, it is made to appear stronger in absolute measure, as expressed by the formula,

$$g = \frac{T\, r \text{ tang. } w}{2\,\pi}$$

According to this formula the value of the force of the current is very easily obtained, if the correct value of T be ascertained; that is, if at the place of observation the horizontal part of the intensity of the earth's magnetism, expressed in absolute measure, be known.

The determination of T (Müller's Lehrbuch der Physik, 3d Aufl. 2 Bd.) has for special physicists no great difficulty, but for many artisans who wish to determine the power of their batteries it is too complicated; at least it is more difficult than the comparison of the data of a rheometer as made by Jacobi, with the chemical effect of the current. It would not be necessary to determine the value of T by experiment at the place of observation; it might be derived from the magnetic chart of Gauss, if it were certain that at the place of observation the effect of the horizontal magnetism of the earth was not modified by iron deposited in that locality, which would produce a considerable deviation from T. For instance, we have from Gauss' chart, as well as from direct observation made in the open air, that for Marburg T = 1.88, while Kasselman found the value of T, in the locality in which he instituted the experiments for comparing the force of the currents of different galvanic batteries, equal to 1.83, (Über die galvanische Kohlenzink Kette von Kasselman: Marburg, 1844, p. 75); hence it is unavoidably necessary to determine the value of T in the locality in which the experiments on the strength of currents are instituted.

Weber's unit decomposes 0.000009376 grammes of water in one second; in one minute 0.00056256 grammes; or, what is the same, it yields 1.0477 cubic centimetres of detonating gas per minute.

To determine the force of a current according to this measure, a tangent compass of Weber is needed, whose ring should not be less than 40 centimetres in diameter, while rheometers of different kinds can be used if the unit of the current yielding one cubic centimetre per minute of detonating gas be adopted.

Let us now examine the process for obtaining the readings of the rheometer with this unit.

§ 8. *Determination of the force of a current by its chemical effects.*—To reduce the magnetic action of the current in the rheometer to the chemical effect, the current has only to be passed simultaneously through a decomposing apparatus and the rheometer; a voltameter which gives the two gases together a detonating mixture, is the best adapted for this purpose.

A current which, for instance, passed through a Mohr's torsion galvanometer, and a decomposing apparatus, produced 40 cubic centimetres of detonating gas per minute, while the corresponding torsion of the galvanometer amounted to 490°.

Since the torsion is in this instrument proportional to the force of the current, we should have, for forming one cubic centimetre of the gas, a current corresponding to a torsion of $\frac{490}{40} = 12^\circ.2 \ldots$; or each degree of torsion should be equivalent to $\frac{40}{490} = 0.0816$ cubic centimetres of detonating gas. To reduce the number of degrees read on this galvanometer to Jacobi's unit, the former need only be multiplied by 0.0816. Hence a torsion of v° is equivalent to the force $0.0816\ v$.

The process is exactly the same for reducing the data of the tangent compass to the chemical effect. In such an instrument, for instance, a deflection of 22° was observed, while 30.8 cubic centimetres of gas were developed. The temperature being 15° Centigrade and the height of the barometer 740 millimetres, the quantity of this gas reduced to 0° Centigrade and a pressure of 760 millimetres is 28.18 cubic centimetres.

Since in this instrument the forces of currents are proportional to the tangent of the angle of deflection, the tangent of 22° or 0.404 corresponds to the quantity of gas, 28.18; and the tangent 1 corresponds to the quantity $\frac{28.18}{0.404} = 69.7$; thus the tangent of any angle of deflection read on this instrument has to be multiplied by 69.7 to find out how many cubic centimetres of detonating gas the current would have produced per minute, if it had passed with the same force through a decomposing apparatus; hence the force 69.7 *tang. v* corresponds to the angle of deflection *v*, according to our chemical unit.

It is easy to reduce the indication of a compass of sines to this unit in a similar manner.

The factor by which the indications of a rheometer are to be multiplied, to obtain the force of current expressed in chemical measure, must of course be determined with great accuracy, for which a single experiment is not sufficient; a series of experiments must be made with currents of different forces, computing the factor from each, and from the values thus obtained the mean is to be taken. The different current forces are most easily obtained by operating, first with a battery producing a strong decomposition of water, and then weakening the current by removing single elements at a time.

Such a series, instituted by Mohr with his torsion galvanometer, gave the following results:

No. of cells.	Torsion of Galvanometer.	Gas developed per minute.	Quantity of gas corresponding to one degree of torsion.
	°	*Cubic cent.*	
8	530	44.5	0.08399
8	587	46	0.07836
8	429	37	0.08624
7	520	41	0.07884
7	490	40	0.08163
7	409	33.5	0.08278
6	423	35	0.08278
6	357	30	0.08403
5	338	29	0.08508
5	337.5	28.5	0.08444
5	315	26	0.08254
4	277	23.5	0.08483
4	263.5	23	0.08728
3	181	16	0.08838
3	181	15.75	0.08701
3	174	15	0.08621
2	85	7	0.08235
		Mean.......	0.08386

Since the magnetic and chemical effects are always proportional to each other, the quotient of the quantity of gas divided by the number of degrees must always be the same, if there are no errors of observation; but this is only approximately the case. The mean of all the quotients is 0.08386; thus we get the current force expressed in chemical measure, by multiplying the number of degrees v read on the instrument, by 0.08386, or,

$$S = 0.08386\, v.$$

Let us now consider a similar series of experiments, instituted to determine the relation of two tangent compasses to the chemical unit. The current was passed simultaneously through a decomposing apparatus and the two compasses, the larger of which had a ring 38 centimetres in diameter, the smaller one of 30 centimetres. That the needles of the two compasses might have no influence upon each other, they were placed twenty-five feet apart. The following are the results of the observation:

No. of cells.	Deflection.		Quantity of gas developed in three minutes.
	Large compass.	Small compass.	
	°	°	
12	28.5	31.	125
8	24.8	27.35	106
6	22.	23.5	92.5
4	18.75	20.4	78.
3	13.75	16.07	56
2	5.9	6.5	23.7

During the period of the experiment, three minutes, in which the gas was caught, the needle vibrated very little; it receded regularly, but the rate was at most 0°.5 in three minutes. The number of degrees of the table are the means of all the angles read from the beginning to the end of the three minutes.

The quotient obtained by dividing the quantity of gas for *one* minute by the tangent of the corresponding angle of deflection should be properly a constant quantity, indicating how much gas a current develops per minute, which produces in the tangent compass a deflection of 45°, (because *tang.* $45° = 1$). The following values of these quotients were obtained from the different experiments:

No. of observation.	Quotient for the	
	Large compass.	Small compass.
	°	°
1	76.7	69.3
2	76.5	71.0
3	76.2	70.9
4	76.6	69.8
5	76.3	69.3
6	76.6	69.3
Mean	76.5	70.

During the experiments the temperature of the room was 15° Cent., and the height of the barometer 744 millimetres. The gas was caught in a graduated tube, and the surface of the water in the tube stood about ten centimetres higher than that without, which is equivalent to a pressure of seven millimetres of mercury. Hence the gas sustained a pressure of 733 millimetres. Reduced to 0° Cent. and a barometric height of 760 millimetres, the quantities of gas, 76.5 cub. centimetres and 70 cubic c., obtained from the observation at 15° Cent., and 733 millimetres, are respectively 69.94 and 64.01 cubic centimetres, or, in round numbers, 70 and 64.

Thus a current which produces in the large compass a deflection of 45° will yield 70 cubic centimetres per minute; one producing in the small compass the same deflection will yield 64 cubic centimetres per minute of detonating gas, at 0° Centigrade, and under a pressure of 760 millimetres.

Hence, in chemical measure the force of a current which produces a deflection of $v°$ in the large tangent-compass is,

$$S = 70 \text{ tangent } v.$$

A current producing a deflection of w degrees in the small compass has, in chemical measure, a force—

$$S' = 64 \text{ tangent } w.$$

The constant factor for the reduction of the reading of a torsion galvanometer, a Weber's tangent-compass, or a compass of sines, may be obtained by a series of very simple experiments. It is perfectly evident that this factor holds good for only a special rheometer, and for that special instrument only as long as the experiment is made in the same place. For instance, if the compass were removed from Freiburg to Marburg, the reducing factor would receive another value, because the horizontal intensity of the earth's magnetism is less in Marburg, and thus a current producing less detonating gas, would still produce a deflection of 45°.

The above series of observations also present us with a proof that Weber's tangent-compass can be used for determining the current force in absolute measure only when its diameter is not much less than 40 centimetres, (the length of the needle being three centimeters.) According to formula 4, the force of a current is proportional to the radius of the ring, the angles of deflection of the tangent compass being equal. The currents which produce a deflection of 45° in the two compasses above mentioned, are to each other in the proportion of 38 to 30. The quotient of these diameters is 1.2666, while the quotient of the corresponding forces of the current is $\frac{70}{64} = 1.0937$.

Having determined the reducing factor of a large tangent-compass by accurate experiments, we can compute from it the horizontal intensity of the earth's magnetism at the place of observation. The current which produces a deflection of 45° in our large compass, (380 millimetres in diameter,) has, in chemical measure, the force of 70; in absolute measure the force is,

$$g = \frac{T : 190}{2 : 3.14}$$

But chemical measure is to the absolute measure as 1.0477 : 1; therefore in absolute measure this current has the value $\frac{70}{1.0477} = 66.813$; and we have,

$$66.813 = \frac{T : 190}{2 : 3.14}$$

Hence,

$$T = 2.2083.$$

According to the chart the value of T at Freiburg is 2.21, which accords very well with that computed above.

To determine the quantity of chemical effect which a current produces, we might, instead of measuring the quantity by the volume of explosive gas evolved, determine the quantity by weight of water decomposed, as Kesselman has done, (Über die galvanische Kohlenzink Kette,) and from that compute the volume of gas evolved. This method of observing is susceptible of great accuracy, and it is to be recommended on that account to those having an accurate balance at command. The experiments given above prove that the direct measurement of the volume of gas also yields very accurate results.

§ 9. *Resistance of the element.*—The force of current of a galvanic combination can be measured directly by means of a rheometer, and reduced in accordance with the principles stated above, to a determinate unit, for which the chemical unit is preferable on account of its simplicity. But the knowledge of the force which the apparatus yields in a special case, with a definite quantity of contingent resistance, is not sufficient for determining the effect of the apparatus in all cases; for this purpose the actual resistance of the battery and its electro-motive power must be known. We now pass to the determination of the actual resistance.

The resistance, as well as the force of the current, must be reduced to a definitive unit, to admit of the comparison of different experimenters. For this, also, different units have been proposed and used. Many physicists assume *as a unit of resistance, the resistance of a copper wire one metre long and one millimetre in diameter.* This unit I shall adopt.

To determine the resistance of a battery, the force of its current, of course, must be measured, if different resistances are inserted successively in the circuit.

The resistance of the inserted piece of wire must be first brought to the adopted unit. The simplest way of doing this would be to use only copper wire of one millimetre in diameter and of different lengths; for a piece 10, 15, 20, &c., metres long, of this normal wire, the resistance would be 10, 15, 20, &c. But, since it is difficult to obtain wires having exactly this diameter, it must be measured accurately, and the computation made how long a copper wire one millimetre in diameter should be, which makes the same resistance. In computing the actual resistance of the battery, this reduced length of wire is used.

This section of our normal wire has a surface of 0.785 square millimetre. Since, with equal resistance the length of the wire increases in proportion to its section, it is evident that a copper wire l metres long, with a radius r, and section πr^2, excites the same resistance as a normal wire of the length,

$$L = \frac{l\,0.785}{\pi r^2}$$

in which L is the reduced length of the wire. A wire, for instance, having a diameter of 0.74 millimetre, a section of 0.43 square millimetre, and a length of 6 metres, will exert the same resistance as a copper wire $\frac{6 \times 0.785}{0.43} = 10.95$ metres long and 1 millimetre in diameter; thus 10.95 is the reduced length of the wire used in the experiment.

From this inserted copper wire many pieces of different lengths may be obtained, 5, 10, 20, &c., metres long, for similar experiments, and ready at all times. Instead of longer copper wires, short pieces of wire of badly conducting metals, as platinum, iron, or German silver, are best; their resistance reduced to the normal wire must be determined by experiment. Wires to about 10 metres long can be wound suitably into coils and fixed in wooden cylinders from 2 to 3 inches in diameter, and corresponding lengths. Longer wires are covered with silk and wound on wooden rollers and used thus. On these cylinders or rollers, the length of the wire reduced to the normal wire can be written so that there will be no further necessity for a reduction of the inserted wire.

Fig. 6.

For inserting wires conveniently into the circuit, a binding screw, such as represented in Fig. 6, may be used. No extended explanation of its application is needed.

Fig. 7.

For fastening thick wires in the holes of the binding screw, they should be at least one line in diameter. But the retaining of these wires is thus rendered somewhat difficult, and in frequent use there is danger in squeezing off their ends. Since the insertion wire must not be too thick, and should always have the same length, it is well to solder the ends of the wire to a piece of copper or brass about 2.5 millimetres thick, which can be easily fastened in the holes of the clamp.

Fig. 8.

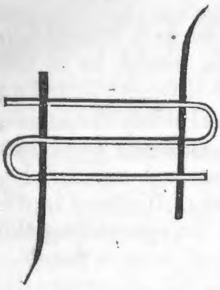
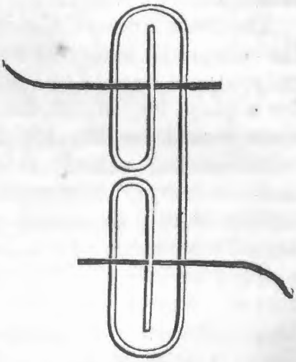


Fig. 9.



Nörrenburg used for metallic connexion of pieces of wire, wire-feathers (Drahtfedern) such as represented in Fig. 9. These wire-feathers are to be recommended because connecting and separating, by means of them, can be done very easily and rapidly.

It is very evident that for insertions, wire of different lengths can be applied advantageously to a rheostat.

Denote by E the electro-motive force of the galvanic battery, by R the essential resistance to conduction; then we have, according to Ohm's law, the force of the current,

$$s = \frac{E}{R} \qquad (1)$$

with perfect metallic closing—that is, with such closing that its resistance to conduction, compared with that of the elements, may be disregarded. Introducing the reduced length of wire l, the force will be only

$$s' = \frac{E}{R + l} \qquad (2)$$

We have here s and s' given by observation; l is also known, and from these two equations E can be eliminated, and the value of R computed. The following tables give a series of observations instituted for determining the resistance to conduction of different batteries:

BUNSEN'S BATTERY, BY DELEUIL.

No.	Insertion in metres.	Deflection.	Tangent of deflection.	Force of current.	R.	E.
		° ′				
1	0	33 30	0.7133	49.931	16.8	883
	68.7	8	0.1405	9.835		
2	0	24 52	0.463	32.41	27.16	880
	7.2	20 7	0.366	25.62		
3	0	24 52	0.463	32.41	26.10	847
	50.7	9	0.158	11.06		
					Mean......	855
4	0	57	1.54	107.8	7.44	802
	7.2	38	0.781	54.67		
5	0	57	1.54	107.8	7.72	832
	29.2	17.8	0.321	22.47		
6	0	57	1.54	107.8	7.74	834
	49	11.8	0.21	14.7		
					Mean......	823
	Mean of the observations....................................					839

BUNSEN'S BATTERY, BY STÖHRER.

No.	Insertion in metres.	Deflection.	Tangent of deflection.	Force of current.	R.	E.
		°				
1	0	61	1.804	121.24	6.2	783
	68.7	8.5	0.149	10.43		
2	0	31.5	0.613	42.91	18	772
	68.7	7.25	0.127	8.86		
					Mean......	777

GROVE'S BATTERY.

No.	Insertion in metres.	Deflection.	Tangent of deflection.	Force of current.	R.	E.
		°				
1	0	30.8	0.596	41.7	19.4	809
	7.2	23.5	0.435	30.4		
2	0	30.8	0.596	41.7	20.4	851
	29.2	13.7	0.245	17.1		
3	0	30.8	0.596	41.7	19.8	828
	49	9.7	0.171	12		
					Mean......	829

DANIELLS' BATTERY.

No.	Insertion in metres.	Deflection.	Tangent of deflection.	Force of current.	R.	E.
		°				
1	0	32	0.625	43.75	11.1	486
	68.7	5.45	0.101	7.07		
2	0	16.8	0.302	21.14	21.5	454
	7.2	12.75	0.266	15.82		
					Mean......	470

SMEE'S ELEMENT.

No.	Insertion in metres.	Deflection.	Tangent of deflection.	Force of current.	R.	E.
		°				
1	0	26	0.488	34.16	5.3	181
	7.2	12.25	0.217	15.19		
2	0	26	0.488	34.16	7.	239
	29.2	5.25	0.092	15.19		
					Mean......	210

WOLLASTON'S ELEMENT.

No.	Insertion in metres.	Deflection.	Tangent of deflection.	Force of current.	R.	E.
		°				
1	0	23.6	0.437	30.58	6.3	193
	7.2	11.6	0.205	14.17		
2	0	23.6	0.437	30.58	7.3	223
	29.2	5	0.087	6.12		
					Mean......	208

In the last vertical column are the computed values of the electromotive force, which shall be spoken of later. We must append a few remarks on the separate experiments whose data are given in the tables.

The numbers under the head "Insertion" indicate the *reduced length* of the inserted wire.

The sulphuric acid used in the first experiment with the Deleuil arrangement was diluted with about ten times its quantity of water; in the second and third, the acid was diluted still more. The nitric acid had a specific gravity of 1.18.

In the last three experiments the sulphuric acid was diluted with five times its volume of water, and the specific gravity of the nitric acid was 1.36.

In the experiments with the Stöhrer arrangement of Bunsen's battery, acid like that of the first experiment with Deleuil's was used; the considerable difference in resistance of elements in the two experiments does not depend here upon the nature of the acid, but is occasioned by the porous cells. In the second experiment with the Stöhrer battery, its own excellent cells were not used, but very brittle earthen cells. By using these red earthen cells the resistance of the elements increased three fold, from which we see what an important influence clay cells have upon the resistance of the element to induction, and thus upon the force of the current.

In Daniells' battery the red clay cells were also used; in the first experiment the zinc was placed in a mixture of 1 part sulphuric acid to 10 parts water; in the last experiment, acid which had been already used, and still more diluted, was applied.

To give the tangent compass a secure position, it was placed upon a thick oak board built into the niche of a window, so that walking in the room produced no vibration in the needle. Thick copper conducting wires passed from the tangent compass to the wall, where they were fixed over a door to a table on which the battery stood.

The resistance of all this wire, together with the tangent compass, is equal to 1.75; that is, it is equal to the resistance of a copper wire 1 millimetre thick, and 1.75 metre long. This resistance is in the values of R in the above table, added to the essential resistance of the elements; thus the true values of R are always 1.75 less; hence we have,

For the Deleuil battery—

1. R = 15.05 (10 water, 1 sulphuric acid.)
2. R = 24.88 (acid used already and diluted more.)
3. R = 5.85 (5 water, 1 sulphuric acid.)

For the Stöhrer battery—

1. R = 4.45 (white cells, } 10 water,
2. R = 16.25 (red cells, } + 1 sulphuric acid.

For the Daniells' battery—

1. R = 9.35 (10 water, 1 sulphuric acid.)
2. R = 19.75 (used acid, further diluted.)

The resistance of the element depends upon the nature of the liquid and the size of the pair of plates; hence to be able to compare the conducting capacity of different galvanic combinations properly, the resistance must be reduced to the same sized pair of plates, and thus the surface of the latter with which the experiment is made must be known.

The above mentioned galvanic elements have the following dimensions:

DELEUIL ELEMENT.

Plate.	Diameter in centimetres.	Height in centimetres.	Surface, square decimetres.
Zinc	3.7	10	1.16
Carbon	5.5	9.5	1.61
		Mean	1.38

STÖHRER ELEMENT.

Plate.	Diameter in centimetres.	Height in centimetres.	Surface, square decimetres.
Zinc	5	12	1.88
Carbon	7	15	3.40
		Mean	2.64

DANIELL ELEMENT.

Plate.	Diameter in centimetres.	Height in centimetres.	Surface, square decimetres.
Zinc	15	21	9.76
Copper	10	22	6.81
		Mean	8.34

For height of the cylinder, the height of the part immersed in the liquid is here given. In the Stöhrer carbon-cylinder, the bottom is closed except a hole in the middle, hence the inner surface of the vase must be reckoned as the surface of the carbon.

To compare the surfaces of the different elements more conveniently, the mean is determined from the positive and negative cylinder; we will term it the mean surface of the element. Reduced to one square decimetre of mean surface, we get the following resistances:

a.	Deleuil's element	21.
b.	Stöhrer's "	12.
c.	Stöhrers' "	43.
d.	Daniells' "	78.
e.	Wollaston's "	13.6.

With equal surfaces, the resistances of the elements were in the ratio of these numbers.

The value 21 of the resistance of the Daniell element for one square decimetre of mean surface, refers to the case in which the zinc cylinder is immersed in a mixture of one part sulphuric acid to ten parts water.

The numbers given for the Stöhrer element refer to the same liquid, and the number opposite *b* to Leipsic cells; that opposite *c* to red clay cells. The resistance of Daniell's battery holds good for the same strength of sulphuric acid, and for red cells.

With equal surface and like liquid, the resistance of the Deleuil element *a* is to the Stöhrer element as 21 : 12; thus the discrepancy is purely in the dissimilarity of the clay cells.

By using red clay cells (*c*) instead of white, (*b*,) the resistance to conduction is increased in the ratio of 12 : 43, or 3.6 times greater. Thus it may be expected, that, by using Leipsic clay cells, the resistance of the zinc and copper battery will be 3.6 times less than by using earthen cells, or for one square decimetre of mean surface, $\frac{78}{3.6}=21.6$.

The Wollaston element was immersed in a liquid composed of one part sulphuric acid to twenty parts water. When one square decimetre of zinc was used, the mean resistance was 6.8. But since each surface of the zinc is effective, 6.8 is the resistance for an effective zinc surface of two square decimetres; thus, for one square decimetre the resistance is 13.6; for stronger acids the resistance would naturally decrease considerably.

§ 10. *Electro-motive force.*—By means of the two equations, (1) and (2), the resistance R of the element, as well as the electro-motive force E, can be computed. From the measurements already given above, we get the values of the electro-motive force of the zinc and carbon batteries of Stöhrer and Deleuil, and of the zinc and copper batteries, as they are presented in the tables under E, namely:

For the zinc and carbon battery of Deleuil—

883
880
847

Mean.............................. 855

For the zinc and carbon battery of Stöhrer—

783
772

Mean.............................. 777

For the zinc and copper battery—

486
454

Mean.............................. 470

The values of the electro-motive force of one and the same battery are very nearly equal, although the nature of the liquid, and with it the resistance to conduction, may change. In fact, the electro-motive force of the Stöhrer zinc and carbon battery differs only 0.1 part from the force of that constructed by Deleuil. This fact has already been mentioned more at length above.

It is now to be explained what we are to understand by these numbers. The electro-motive force is that force which sets the current in motion. We can of course measure this force, as well as that of the current, by its effects.

The electro-motive force of the voltaic pile is proportional to the electrical tension of the pole in the open circuit; we could, therefore, apply this tension as a measure of the electro-motive force, if the electrical tension were not so very small at the poles that it cannot be determined with much accuracy in batteries of a few pair of plates or elements. But Ohm's law teaches us that the force of the current of the closed battery is also proportional to the electro-motive force; and since the power of the current can be measured with great accuracy and reduced to a definitive unit, it is better to use the force of the current as a measure of the electro-motive force. We have

$$S = \frac{E}{W}$$

in which W denotes the entire resistance which the current has to overcome; when $W = 1$, we have

$$S = E.$$

E is here the force of the current which the battery would give if the resistance to conduction were $= 1$. In establishing our units of force of current and resistance, let us consider *the value of electro-motive force,* or the value of E, *as the quantity of detonating gas which the current of a battery would give if the whole resistance were equal to the resistance of a copper wire* 1 *metre long and* 1 *millimetre thick;* thus if we have found the electromotive force E of Daniell's zinc and copper battery to be 470, it means that the current of Daniell's battery would give 470 cubic centimetres of detonating gas per minute if the sum of all resistance were equal to the above-mentioned unit of resistance.

I consider it a great advantage of the chemical unit of force of current recommended above (= that current which yields one cubic centimetre of detonating gas per minute) that in adopting it the values of the electro-motive force are not barely proportional numbers, but that each has for itself a perfectly distinct and easily comprehended signification.

Although Jacobi was the first, to my knowledge, to attempt the reduction of the data of the galvanometer to the chemical effect, he did not make any further use of this chemical unit of the force of the current—that is, he did not apply it to the computation of the electro-motive force.

§ 11. *The electro-motive force is proportional to the tension of the open circuit.*—It has been already mentioned that the electrical tension at the poles of an open battery may be considered as a measure of the electro-motive force. The correctness of this assumption has been tacitly received by most physicists, although a direct experimental confirmation had not been attempted on account of the imperfection of the apparatus. Kohlrausch has at length supplied this omission. He converted the exceedingly sensitive electrometer of Dellman into a measuring instrument of great accuracy. By combining this instrument with a condenser (Pog. Ann. LXXV, 88) he succeeded in determining the electroscopic tension at the poles of an open, simple battery, with such exactness that there can be no longer any doubt of the correctness of the above-mentioned principle.

Kohlrausch has, at the same time, proved by this investigation that Dellman's electroscope, as it comes from his hands, is adapted to the most delicate electrical researches. For a more detailed description of the instrument and its use, we refer the reader to the excellent treatise already cited. The comparison of the electromotive force with the tension of an open battery may be found in a third memoir in volume LXXV of Poggendorff's Annalen, page 220. To render the results of this investigation comprehensible, we must first give the *modus operandi* more fully by which the values of the electroscopic tension can be derived from the measurements made by the instrument.

Kohlrausch's electrometer can be used as a measuring instrument in two ways, namely:

1. By placing the upper divided circle, which we shall term the torsion circle, at 90°, the movable needle will form an angle of 90° with the fixed metal strip. The needle and strip are now brought into communication, the electricity to be measured communicated to them, and then the connexion between needle and strip broken. The torsion circle being now turned back to 0, the needle will form an arc with the strip as much greater as the electrical charge is stronger.

The electrical charge which produces a deflection of 10° being denoted by 1, the strength of the electrical charge belonging to each angle of deflection can be determined. For the details of this computation I refer the reader to Kohlrausch's memoir in volume LXXII of Pogg's Ann. On page 385 he gives a table, indicating the corresponding electrical tension for each angle of deflection, which holds good, of course, only for his own instrument. For clearer comprehension of the matter we will present an extract from this table:

Angle of deflection.	Strength of Electrical tension.
10	1.00
20	1.94
30	3.06
40	4.39
50	6.10
60	8.30
70	11.40
80	18.33

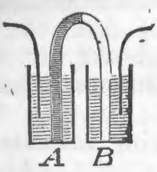
Thus if the charge which produces 10° of deflection be denoted by 1, the electrical charges, which produce 40°, 60°, and 80°, are respectively equal to 4.39, 8.30, and 18.33.

Kohlrausch's table gives results for whole degrees.

2. The instrument can be applied in a second manner for measuring electrical charges. If after placing the needle and strip at right angles, both being in communication, electricity is imparted and the connexion then broken, we are able, by turning the torsion circle, to make the angle of deflection a constant quantity, say 30°. According to well known principles the electrical charge is then also proportional to the square root of the torsion necessary to maintain the needle at the deflection of 30°.

Kohlrausch determined the tension at the poles of different simple batteries by both methods; the batteries being arranged as follows: The two metals were soldered together; one was immersed in the liquid of the vessel A, (Fig. 10,) the other in the liquid of the vessel B; in each vessel a brass wire was placed, forming the poles. One of the wires was connected with the ground, the other with the collector-plate of a condensing apparatus. The tension of the positive as well as of the negative pole was determined for each battery by many experiments, and the mean of all taken.

Fig. 10.



The electro-motive force of the different galvanic elements Kohlrausch determined according to Wheatstone's method, which will presently be mentioned. The following table contains the results of his measurement:

Description of battery.	Electro-motive force.	Tension of open battery.	
		I.	II.
1. Zinc in sulphate of zinc; platinum in nitric acid of density 1.357	28 22	28.22	28.22
2. Zinc in sulphate of zinc; the nitric acid of 1.213 sp. gr.	28.43	27.71	27.75
3. Zinc in sulphate of zinc; carbon in nitric acid of 1.213 sp. gr.	26.29	26.15	26.19
4. Zinc in sulphate of zinc; copper in sulphate of copper	18.83	18.88	19.06
5. *a.* Silver in cyanide of potassium—common salt; copper in sulphate of copper	14.08	14.27	14.29
b. The same, later	13.67	13.84	13.82
c. The same, still later	12.35	12.36	12.26

The tension of the open battery is determined by the above-described methods. The numbers under I and II were obtained by the first and second methods respectively.

Since the square roots of the torsions, as well as the numbers of the table on page 385 of volume LXXII of Pogg. Ann., denoting the tensions corresponding to the different angles of deflection, and also the number expressing the electro-motive force, are all measured by different units, Kohlrausch, in order to make the data comparable, has multiplied the roots of the torsions by 1.0239, the values determined by the angle of deflection by 1.8136, by which means the results by the first experiment are rendered perfectly accordant. But since the rest of the corresponding numbers accord *very* closely, these experimental series prove *that the electro-motive force is proportional to the electroscopic tension at the poles of the open battery.*

This principle might be proved with less sensitive electrometers, by determining the tension at the poles of a battery of 30, 40, or more, elements.

Kohlrausch's instrument is also very well adapted to solve a disputed theoretical question, to which allusion has been made above. If a strip of zinc and one of platinum be immersed in a vessel of water without touching each other, according to Schönbein's view, the upper end of the zinc must indicate free negative electricity—the upper end of the platinum, free positive; while according to the contact theory the reverse should be the case. It is very desirable that Kohlrausch himself should investigate this, because he not only possesses an excellent instrument of the kind, but has attained great skill in manipulating with the apparatus.

§ 12. *Indirect methods for determining the constants of the battery.*—The process given above, derived from formulas (1) and (2), for determining the resistance and electro-motive force of a galvanic battery, and that for determining the constants, which we will call Ohm's method, is as simple as it is accurate, if a suitable measuring apparatus is furnished, and a battery sufficiently constant be used. Both, however, were wanting at the time of the publication of Ohm's law, and it thus happened that complicated methods had to be used to obtain only tolerably accordant results. By degrees only, simplicity was attained in this instance, as is often the case in the history of physics.

First, there was wanting an instrument adapted to measuring the force of current; then the multipliers used were objectionable in two particulars: they were suited for weak currents only, and there was no simple law, showing the relation of the angle of deflection and the force of the current.

Several physicists have proposed very ingenious methods for graduating a galvanometer; that is, to determine empirically what relation the different degrees of deflection have to the force of current; yet since they do not appear to be very well adapted for general use, and only yield useful results in the hands of skilful experimenters, I may be pardoned for not going into the details of these methods of graduating. The method which Poggendorff has given for converting the galvanometer into a measuring instrument, is found in volume LVI of his Annalen, page 324. There is also in this paper a short collection of the methods recommended by other physicists for the same purpose, with indications of the sources, to which I must refer those who wish to enter into the details of this subject.

Fechner did not use the deflection of the needle for determining the force of current, but the period of oscillation of the needle about its position of equilibrium, for the case in which the coils of the multiplier are parallel to this position.

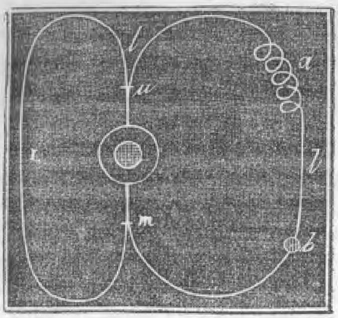
This method is too laborious for general use.

Thus, methods for determining the constants of the battery (electro-motive force and resistance) were sought for, which do not require the knowledge of the force of the current. These efforts were even continued after Pouillet's and Weber's tangent compass, as well as the compass of sines, were known. It is really surprising that such important instruments as these, which introduced so great simplicity into the study of galvanic laws, were so slowly adopted and so generally applied.

We shall now consider more closely the best of these indirect methods.

Jacobi presents the following: (Pogg. Ann. LVIII, 85.) The conducting circuit of the battery is divided into two parts, as shown in Fig. 11. Let the resistance to conduction of one of the branches be L, that of the other l, in which the rheostat* is inserted at a, the galvanometer at b; then the resistance which these two circuits, inserted at the same time, produce, is—

Fig. 11.



$$\frac{l\,\mathrm{L}}{\mathrm{L}+l}$$

Hence, the whole force of the current which the apparatus yields is—

$$\mathrm{S}=\frac{\mathrm{E}\,(\mathrm{L}+l)}{\lambda\,(l+\mathrm{L})+l\,\mathrm{L}}.$$

Denoting, by λ, the resistance of the elements, (including the conductor between m and u.)

The part of the entire current which passes through the galvanometer is—

$$\mathrm{S}'=\frac{\mathrm{E}\,\mathrm{L}}{\lambda\,(\mathrm{L}+l)+l\,\mathrm{L}}.$$

Breaking the lateral closing, the force of the current in the other circuit will increase, and we must add the resistance x by means of the rheometer, to restore the galvanometer needle to its former position; but we have now for the force of S′ the value—

$$\mathrm{S}'=\frac{\mathrm{E}}{\lambda+l+x}.$$

From this and the previous equation we get for λ the value—

$$\lambda=\frac{x\,\mathrm{L}}{l}.$$

Now, since x, L and l are known, the resistance of the elements can be determined by this method, without knowing the value of the force of current.

---

* An account of this instrument is given at the close of this section.

If another battery, whose resistance is λ', with the resistance l' and x', (quantities corresponding to the l and x above,) produce the same deflection in the galvanometer, we have—

$$S' = \frac{E'}{\lambda' + l' + x'};$$

Hence

$$E : E' = (\lambda + l + x) : (\lambda' + l' + x'.)$$

Thus by this method the relation of the electro-motive forces of different voltaic combinations to each other can be determined. Jacobi found, in this manner, that the electro-motive force of Daniell's battery is to that of Grove's as 21 is to 35.

Wheatstone presented a very beautiful process for determining the electro-motive force of a battery, without having previously found a value for the resistance of the battery. (Pogg. Ann. LVII, 518.)

A battery whose electro-motive force is E, gives as the force of the current

$S = \frac{E}{R}$, R being the sum of all the resistances. The electro-motive force of another battery being n times as great, the entire resistance must also be n times as great if the second battery has the same force of current, or produces the same deflection (say 45°) in the galvanometer; then we have

$$\frac{E}{R} = \frac{n\,E}{n\,R}$$

Adding to the resistance R the resistance r, the force of the current will decrease to $\frac{E}{R + r}$; the needle of the galvanometer will recede a given number of degrees, (say 5°.) If it be desired upon inserting the second battery to weaken the current exactly so much, and make the needle recede from 45° to 40°, the resistance $n\ r$ must be added to the resistance n R; for if $\frac{E}{R} = \frac{n\,E}{n\,R}$ we have also $\frac{E}{R + r} = \frac{n\ E}{n\ R + n\ r}$. The electro-motive forces of the two batteries are consequently to each other as the resistances which must be added to the resistance already present, to cause the needle to retrograde from a given deflection (say 45°) a given number of degrees, (say 5°.)

To compare the electro-motive forces of different batteries the following process is, therefore, to be adopted. In the conducting circuit of the battery, besides the galvanometer, the rheostat is inserted with so much wire as to produce a deflection of the needle of 45°; the resistance is then increased by turning the rheostat until the deflection of the needle is only 40°; the number of turns is thus a measure of the electro-motive force of the battery.

Suppose, for example, the current of a Daniell's element be passed through the rheostat and the galvanometer, and so much wire has been inserted as to produce the deflection of 45°. To reduce the deflection from 45° to 40°, suppose thirty turns of the rheostat must be added. Now insert a Grove's element into the same circuit, and so regulate the entire resistance that the needle stands again at 45°. To bring it down to 40° the resistance must be increased by (say) fifty turns of the rheostat; then the electromotive force of Daniell's battery is to that of Grove's as 30 to 50. This is evidently the simplest process for determining the ratio of the electro-motive forces of different batteries.

Wheatstone used a multiplier as a rheometer, and on that account had to insert a considerable resistance to make the current of the hydro-electric elements weak enough. Under these circumstances, of course, only a rheostat with a thin wire can be used.

Although this method was originally designed for a multiplier, it may be also used with any other rheometer, as the torsion galvanometer, tangent compass, &c. But with these instruments, which admit of stronger currents, the current used need, of course, not be very weak, and therefore a rheostat with a thicker wire can be used.

This method of Wheatstone gives us the values of electro-motive force measured by the length of wires required to effect the retrogression of the needle; hence these numbers are dependent on the individuality of the galvanometer and the rheostat.

As examples of his method, Wheatstone adduces the following measurements. Three small Daniell's batteries* of unequal size were in succession brought into the circuit. To revert the needle from 45° to 40°, the following number of turns of the rheostat were necessary:

Copper	cylinder	1½	inch	high,	2	inches	diameter,	30	turns.
“	“	3½	“	“	2½	“	“	30	“
“	“	6	“	“	3½	“	“	30	“

Thus the electro-motive force, according to the theory, is independent of the size of the pair of plates.

When batteries of 1, 2, 3, 4, 5 equal elements were used as electro-motors in succession, the following results were obtained:

1	element	required	30	turns.
2	“	“	61	“
3	“	“	91	“
4	“	“	120	“
5	“	“	150	“

Thus the electro-motive force of the battery is, as theory indicates, proportional to the number of pairs of plates.

I have determined by this method the electro-motive force of a Daniell's, a Grove's, a Stöhrer's, and a Deleuil's element, using for this purpose the tangent compass, and a rheostat with thick wire.

For bringing the needle back from 15° to 10°, I found as follows:

With	Daniell's	element,	9	turns.
“	Grove's	“	13	“
“	Stöhrer's	“	13.6	“
“	Deleuil's	“	15.1	“

---

* The elements were somewhat differently constructed from those of the ordinary Daniell's battery. The porous clay cell contained only liquid zinc amalgam, and it, as well as the cylinder of copper surrounding it, stood in a solution of sulphate of copper.

The electro-motive force of Deleuil's battery was determined by the chemical method at the same time. The results of these determinations have been given in a previous table. Of the six measurements of Deleuil's battery, the last three belong to this series.

After these determinations, it is easy to reduce the number of turns necessary to revert the needle from 15° to 10°, to the unit of electromotive force described above. We have—

15.1 turns, equivalent to 823 of electro-motive force;
hence 1 " " 54.51 " "

Thus the values determined by revolution of the rheostat expressed in our unit, are as follows:

For Daniell's battery	490.
" Grove's "	709.
" Stöhrer's "	741.

The zinc of Daniell's battery during the last measurement was in stronger sulphuric acid, for which case the direct measurement had given the value 486. The electro-motive force of Stöhrer's battery was previously found somewhat greater. The numbers for Grove's battery differed considerably, on which account no dependence can be placed upon them.

In the same manner as here, values of electro-motive force, connected with the individuality of the instrument, may be reduced to our unit, provided the corresponding factor has been determined.

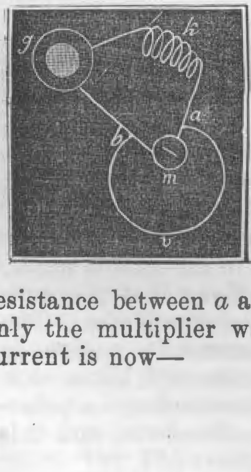
To determine the resistance of the element, Wheatstone has given several methods, the first of which only we will present here.

Place the galvanometer and rheostat in the circuit, and so adjust the latter that the needle of the former stands at a given point. The force of the current S is—

$$S = \frac{E}{R + g},$$

denoting by E the electro-motive force, by g the resistance of the multiplier, by R the whole of the remaining resistance in the circuit. This arrangement is rendered clear by Fig. 12, g representing the galvanic element, k the rheostat, m the multiplier.

Fig. 12.



Making a branch to the current passing through the galvanometer, by a wire whose resistance is exactly equal to the resistance of the multiplier, one-half of the current will reach b from a through v, the other half will pass through the galvanometer to b. The resistance between a and b is now just half as great as before, when only the multiplier was present; hence the power of the undivided current is now—

$$\frac{E}{R + \frac{1}{2} g}$$

one half of which passes through the multiplier, and the power of the current passing through this instrument is now only

$$S' = \frac{1}{2} \frac{E}{R + \frac{1}{2} g};$$

but the needle can be restored to its original position by suitably diminishing the resistance R by means of the rheostat. If by turning it, the resistance of the undivided part of the circuit is reduced from R to ½ R, the strength of the current is

$$S'' = \frac{1}{2} \frac{E}{\frac{1}{2} R + \frac{1}{2} g} = \frac{E}{R + g}$$

therefore it is again as strong as at first. Hence, if after the insertion of the branch wire v, a number n of coils of the rheostat must be taken out of the circuit to recover the original deflection of the needle, then the resistance R of the undivided part of the circuit is equal to that of 2 n coils.

But the resistance R consists of two parts—the essential resistance of the element, and the resistance of the conducting wire from one pole to a, and from the other to b. The resistance of these wires has to be determined and subtracted from R to find the essential resistance of the element.

This, as well as all other indirect methods for determining the essential resistance of an element, is not so simple that it should be preferred to the direct determination described above, if an instrument for *measuring* the force of current is at command.

§ 13. *Poggendorff's method for determining the electro-motive force of inconstant batteries.*—In volume LIII of his Annals, page 436, Poggendorff communicates his first experiment on the electro-motive force of the zinc and iron battery. Although iron is much nearer to zinc in the tension series than copper, yet the current which the combination of zinc and iron produces in dilute sulphuric acid, is stronger than the current of an element of copper and zinc in the same liquid and under like circumstances.

This result at first glance appears to be in opposition to the contact theory; hence Poggendorff undertook a more exact investigation. He determined, as well as it is possible with the changeable current of batteries with one liquid, the resistance and the electro-motive force of both combinations, by Ohm's method, and found, that in fact the electromotive force of the zinc and iron battery was to that of the zinc and copper as 21.5 to 11.8.

Thus the electro-motive force of the zinc and iron battery is actually greater than that of the zinc and copper, though in the tension series, iron stands between zinc and copper. Poggendorff saw that the cause of this anomaly could only be the polarization of the plates. The electro-motive force, which originally set the current in motion, is limited by the electrical difference of the metals in contact; but as soon as the current begins to circulate, the metal-plates undergo a polarization which diminishes the original electro-motive force, and this polarization is greater in the combination of zinc and copper than in that of zinc and iron.

This galvanic polarization we will consider hereafter more at length; it is only mentioned here so far as is necessary to show the course of Poggendorff's investigation.

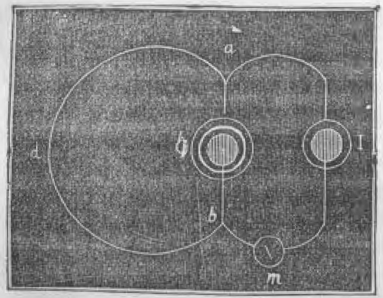
If the values found by Ohm's method for the electro-motive force do not accord with the tension series, the cause, as above remarked, is purely in the modification which the original electro-motive force undergoes by polarization. Poggendorff endeavored to determine *the value of their original electro-motive force before it was modified by polarization.* We will pass by the earlier efforts by which this object was but imperfectly attained, and turn to the consideration of a method which Poggendorff has published in volume LIV of his Annals, page 161.

This method differs essentially from all others, in that not the current of a battery, but only the tendency towards a current, is measured. To avoid polarization, Poggendorff endeavored to prevent the current from coming into action, and to compensate it beforehand by another whose electro-motive force was constant and known.

The arranging and establishing of this compensating method is described somewhat diffusely by Poggendorff, and on that account is not perfectly clear; hence I have departed from his mode of presentation, since it has been an object in this report to make it as intelligible as possible.

In Fig. 13, C represents a constant element—say a Grove's, and I another voltaic element, whose electro-motive force is less than that of C. The positive poles of both are connected by a conductor, and likewise the negative. In the connexion of two poles of like name a multiplier *m* is inserted; the connexion of the other two poles can be broken at *a* at pleasure, and renewed again. The conducting wire *a d b* closes the constant battery C.

Fig. 13.



Suppose the element I is precisely equal to C, and the connexion at *a* is made, this combination, then, is in fact nothing else than two elements so connected that they constitute a single element with a double surface; but, if the electro-motive force of I is weaker than that of C, the actions of the currents are somewhat more complicated.

Denote by—

l, The resistance of the element C, together with the conductors between *a* and *b*.

l', The resistance of the element I with the conductors between *a* and *b*, the resistance of the multiplier included.

r, The resistance of the conducting wire *a d b*.

E, The electro-motive force of C.
E′, The electro-motive force of I.

The current of the element C divides at a and b into two parts; one of which passes through the conductor by d, the other through I. The resistance to conduction of the one branch is r, that of the other is l'; hence the resistance of the two branches together is $\frac{l'r}{l'+r}$ and the undivided current which C produces is—

$$\frac{E}{l+\frac{l'r}{l'+r}}=\frac{E\,(l'+r)}{l\,(l'+r)+l'\,r}.$$

In this we neglect the electro-motive force in I.

The part of the entire current which passes through I is—

$$\frac{E\,r}{l\,(l'+r)+l'\,r}. \qquad (1)$$

The entire current which I produces, and which is divided between the branches a C b and $a\ d\ b$, is—

$$\frac{E'\,(l+r)}{l'\,(l+r)+r\,l}. \qquad (2)$$

The two currents (1) and (2) pass through the multiplier in opposite directions. Since the denominators of the values (1) and (2) are exactly equal, the multiplier evidently will stand at the zero point, if

$$E\,r=E'\,(l+r). \qquad (3)$$

For given values of E E′ and l a value of r can always be found which will satisfy equation (3); that is, there is a certain length of the conducting wire $a\ d\ b$ with which the multiplier indicates no current, when the wire coming from a is brought in contact with one of the poles of C.

If the resistance r be too great, the multiplier will indicate a current in favor of C; on the contrary, the current of C in the multiplier will preponderate if the resistance r is too small.

If the resistance r in the wire $a\,d\,b$ is precisely such that the multiplier remains at zero when the circuit is closed at a, or when equation (3) is satisfied, we get from this equation the following:

$$E'=E\,\frac{r}{l+r}. \qquad (4)$$

We can thus compute the value of E′; that is, the electro-motive force of I, when E, the electro-motive force of C, is known, and also the values of resistance l and r.

The exact length of the wire $a\ d\ b$ cannot be attained at the first trial; in general by closing the circuit at a the needle of the multiplier will be deflected to one side or the other, according as the wire is too long or too short. By a few trials, shortening or lengthening the wire $a\ d\ b$ as may be necessary, it is easy to find such a length that the galvanometer will indicate no current, or at most a very feeble one.

This is to be considered as a first approximation to the correct ratio between r and l. The battery I should now be left open for a time, that it may lose all polarization; or, what would be better, the negative plate should be taken out of the liquid, cleaned, and then restored to its place. If a deflection occurs again on closing the circuit, the length of the wire *a d b* must be regulated until the exact proportion is obtained. The current which the electro-motive force of the element I, unmodified by polarization, tends to generate, is compensated, and the value of E′ can be computed by equation (4).

Poggendorff proved his method by ascertaining with it the electro-motive force of constant elements, which could be determined in another manner, and found perfectly accordant results. He obtained, by Ohm's method—

The electro-motive force of Grove's element.................... = 25.886
The electro-motive force of Daniell's element.................. = 15.435

The Grove's element was then placed at C, and the Daniell's at I, (Fig. 13.) l was 35.03. The equilibrium, above mentioned, took place when $r = 52.68$. For this case we have—

$$\frac{l + r}{r} = 1.668.$$

Hence we get by this method

$$E' = \frac{25.886}{1.668} = 15.51,$$

which accords very well with the value of E′, determined by Ohm's method.

Poggendorff now used this method for determining the original electro-motive force in constant batteries. That of Grove's battery, adopted as the standard of comparison, was found by Ohm's method to be equal to 22.88, and he found for the original force of an inconstant battery, made of

Zinc and copper	13.79
Zinc and iron	7.40
Iron and copper	6.00

These results prove that the original electro-motive force of these combinations very nearly satisfy the law of the tension series, since that of copper and iron, and that of iron and zinc, is nearly equal to the electro-motive force of copper and zinc; thus, $7.4 + 6 = 13.4$, nearly equal to 13.79.

If the current of the zinc and iron battery is stronger than that of the zinc and copper, and if, according to Ohm's method, the electro-motive force of the former combination is found greater than that of the latter, it is solely because the current of the zinc and copper combination generates a stronger polarization, acting against the original electro-motive force, than the current of the zinc and iron battery.

§ 14. *Comparison of different voltaic combinations.*—In the last paragraph we have seen how the constants of a voltaic combination can be determined and expressed in comparable values. None of the statements of the effects of batteries, as they are ordinarily presented for comparison, are satisfactory. The want of accurate numerical determinations occasions great uncertainty in regard to the advantages and disadvantages of different galvanic combinations. If such uncertainty exists in the accounts of men of science, it is not at all surprising to find communications in technical journals, which betray entire ignorance of the principles here discussed.

Let us now examine the most important of the galvanic combinations somewhat more closely.

§ 15. *The simple zinc and copper battery.*—The Wollaston battery is a convenient form of the simple zinc and copper combination, with one liquid.

The batteries of Young and Münch may be considered as variations of Wollaston's, and therefore a description of them is not necessary.

The simple zinc and copper battery, it is well known, is not constant, because the electro-motive force is considerably modified by the polarization of the copper plate, which takes place in consequence of the current. Poggendorff found, as we have seen, the electro-motive force of the zinc and copper battery in dilute sulphuric acid, before being modified by polarization, to be equal to 13.8, while the electro-motive force of Grove's battery is equal to 22.9.

Assuming the electro-motive force of Grove's battery to be 830, referred to the chemical unit, (see table §9,) the unmodified electro-motive force of the zinc and copper battery would be 500 of the same unit. But according to my experiments, when the current commences, the electro-motive force of the zinc and copper combination is only 208; thus, by polarization, the force is very soon reduced to $\frac{2}{5}$ of its original value, and this is also the reason that immediately after immersion the current is exceedingly strong, but then very rapidly decreases. The polarization having once reached its maximum, the current remains tolerably constant—at least, so much so as to admit of accurate measurement. The numbers from which the values previously given (§ 9) of electro-motive force and of resistance to conduction of Wollaston's battery were computed were not immediately observed, but are the means of numerous readings. To form a correct idea of the action of this battery, I will give here the corresponding series of observations entire:

Kind of wire inserted.	Deflection.
0	26°
Copper	12
"	11.5
0	24
Copper	11
"	11.25
0	23.5
Brass	5
0	24
Brass	5
0	22
"	23
Copper	11
0	23

On closing the battery, a few moments elapsed before the needle came to rest, from very rapid oscillation; and even after the oscillation had ceased it went back slowly, and was tolerably stationary at 26°, which is the first entry in the table. A copper wire was then inserted, of which resistance, by previous experiment, had been found equal to that of 7.2 metres of the normal wire. The needle came to rest at 12°, but after a short time went back to 11.5°.

The copper wire was then removed from the circuit, when the deflection was 24°, &c., &c.

The brass wire, which reduced the deflection to 5°, had a resistance equal to that of 29.2 metres of the normal wire.

Thus we see that the current of this element, after the first oscillation, remains tolerably constant—at least, so much so that approximately accurate estimates can be made for computing the electromotive force and resistance to conduction. While, on the one hand, the electro-motive force is considerably weakened by the current, on the other the resistance is not great, even with very weak acid. Where it is not important to make exact measurements, and when a steady current is not required for a long time, the zinc and copper battery may be advantageously applied to many galvanic experiments. If elements with large surfaces are necessary, the form of Hare's spiral is to be preferred.

The force of the polarization is dependent, most probably, upon the strength of the current, though accurate researches on this subject are yet wanting.

The reason why batteries with one liquid are not constant is to be sought in the polarization of the negative plate, and this is obviated as much as possible in the so-called constant battery. Yet the strength of the current of the constant battery gradually decreases, by leaving it closed for a long time, because the liquid gradually changes—the dilute sulphuric acid becoming converted, by degrees, into a solution of sulphate of zinc. A corresponding change in the nature of the liquid takes place in all batteries, without exception, and it is only to be avoided by renewing the liquid from time to time. An arrangement might be so made that the heavy solution of sulphate of zinc would flow off slowly from the lower part of the vessel, and the fresh acid flow in above at the same rate.

A circumstance which acts quite injuriously in all batteries without porous partitions is, that, in consequence of the current, the sulphate of zinc solution is decomposed, and metallic zinc deposited on the negative plate, whence, during a protracted action of the battery, its electro-motive force must decrease more and more.

The constancy of the battery current depends essentially upon its strength. Feeble currents, like those obtained by using very dilute acid, and with great resistance included in the circuit, remain constant for some time; while, by using stronger acid and less resistance, the strength of the current must necessarily decrease far more rapidly. Hence, if it be desired to compare different batteries, with reference to their constancy, equal resistance and like acid must be used. Neglect of these conditions may have been the occasion of numerous rrors in regard to the constancy of single batteries.

Batteries composed of zinc and copper plates buried in the moist ground are said to be very constant. Such batteries, however, yield very weak currents, because the resistance to conduction between the plates is very great. Thus it is evident that the current of this battery will remain constant longer than when the plates were immersed in acid.

Prince Bagration placed plates in vessels filled with sand, which he moistened moderately with a solution of sal-ammoniac. Garnier used such batteries successfully to keep electrical clocks in motion (Dingler's Journal, vol. 110, p. 177); here a very feeble current was powerful enough to impart sufficiently strong magnetism to a small electro-magnet.

Garnier's apparatus was constructed as follows: The sand was in a small tub; the zinc and copper had the form of a cylinder, the zinc being on the inside. The surface of the copper was 1.5 and that of the zinc 1.3 square decimetres. Such an element kept the apparatus in motion two months and a half. By using a battery of many such elements the construction could be so arranged that a single pair of plates might be removed, and renewed without interrupting the current.

Koppinsky (Dingler's Journal, vol. 101, p. 222; Technologiste, March, 1846, p. 241) was disappointed in his expectation of this battery. He probably wished to produce strong currents with it. The vapor of ammonia also annoyed him. The unfavorable results are to be ascribed, in his opinion, to insulation; because the battery cannot supply itself with electricity from the ground, and because it is not protected from exposure to the air, which neutralizes the electricity generated by contact of the plates.

I cite this as an example of the loose and inconsiderate disquisitions on the galvanic current and battery to be met with in technical periodicals. The editors of these journals should be more critical in such cases, and statements which are only calculated to lead astray those having no well-founded physical knowledge should either not be permitted to appear, or should be accompanied with the requisite explanations.

After condemning all other batteries, Koppinsky finally proposes to use for galvano-plastic purposes, zinc and copper elements, the plates of which are one square metre in surface, and immersed two or three millimetres apart in dilute sulphuric acid. This is one of the oldest forms of the battery with large plate, to which Hare subsequently gave the very convenient form of a spiral; thus, in this respect, Koppinsky's efforts resulted in nothing new. On the other hand, the proposal to place the acid in vessels of other than resinous wood and set them on moistened earth, is new, but of no value.

The experiments of Weekes (Dingler's Journal, vol. 97, p. 194) show the feebleness of the current produced by burying in tolerably moist ground, plates of zinc and iron, each being 54 square decimetres in surface. A current was obtained which deflected the astatic needle of a multiplier 87°, but the deflection soon fell to 61°; the current was therefore exceedingly weak.

A pile of 36 pairs of this kind gave, between coal points, a light strong enough by which to read fine print at the distance of $\frac{1}{2}$ a metre. Comparing this exceedingly small effect with the brilliant illumination produced by 36 zinc and carbon, or zinc and platinum elements, it is difficult to comprehend how Mr. Weekes can cherish the hope that such batteries may become advantageous means of illumination.

The plates of Mr. Weekes, it is true, were placed in rather dry ground; if placed in moister ground they would have yielded a stronger current; but it could never be as strong as if the plates were immersed directly in water. By moistening the sand with a solution of sal-ammoniac the strength of the current will still never approach that which the same plates would produce if placed in the solution without the sand. Buried plates can be used profitably only when very weak currents are desired; but such currents can be obtained quite constant for a long time by using very dilute acid. Buried plates, however, have the disadvantage of being less accessible than those of other batteries.

§ 16. *Smee's battery.*—This battery was greatly praised in many quarters; it was represented to produce very strong currents, and to be far more constant than other batteries with one liquid. No measurements in support of this opinion were made, and I have not found it anywhere confirmed.

The copper of Wollaston's battery is substituted in Smee's by platinum or silver, covered by a rough surface of platinum (platinmoor.) This coating of platinum is produced by immersing the perfectly clean plate in a solution of chloride of platinum and potassium in contact with the negative pole of a rather weak battery, the positive pole of which dips at the same time into the solution. The platinum deposites on the plate at the negative pole. If the positive pole be also a plate of platinum, it will be attacked by the chlorine, and the solution will be kept saturated.

The two surfaces of Smee's platinized plate are placed at about one line distance from the zinc plates. The width of the zinc plates is to be only about three-quarters that of the platinized plate. What is to be expected to be gained by this I cannot see. It is not the case in the Smee element with which I experimented, the negative plate of which was platinized silver.

I found this battery less constant than Wollaston's, and the variations of the needle were far greater. With the same liquid, Smee's battery gave the following results, obtained exactly as those already described in section 15.

Kind of wire inserted.	Deflection.	
0	30°	Soon falls to
0	28	
Copper	12.5	
0	28.5	
After a few vibrations—		
0	25.	
Copper	12	
0	25	

Plates washed.

0	28.5
0	26
After many vibrations—	
0	25.
Brass	5.5
—	5
0	29
0	26
0	24

Assuming as a mean for the insertion 0 the deflection 26°, for the copper wire 12°.25, and the brass wire 5°.5, the electro-motive force of Smee's element is 212, which is scarcely greater than that of Wollaston's, which we have seen is 208. With equal surfaces, the resistances of the two elements are tolerably equal. From these experiments, it does not appear that Smee's battery deserves any preference over Wollaston's. It is yet to be determined whether platinized platinum gives better results than platinized silver.

§ 17. *The zinc and copper battery with two liquids.*—When the copper of a zinc and copper battery is placed in a concentrated solution of sulphate of copper, and this in dilute sulphuric acid, the two liquids being separated by a porous partition, the injurious effects of polarization are in a great measure removed ; the electro-motive force becomes greater than in the ordinary zinc and copper battery, and the strength of the current is constant.

The electro-motive force of Daniell's battery is—

$$E = 470.$$

From Svanberg's experiments, (*Pogg. Ann., LXXIII*, 290,) it appears that the electro-motive force of Daniell's battery changes but little with the nature of the liquid. The copper being constantly immersed in a concentrated solution of sulphate of copper, and the zinc immersed in various liquids successively, the following values, expressed in an arbitrary unit, were obtained for the electro-motive force :

For concentrated solution of sulphate of zinc	15.6
For the same, much diluted	15.9
For concentrated solution of sulphate of copper	16.6
For the same, much diluted	16.2
For slightly acidified water	16.0
For more strongly acidified water	16.7

For a square decimetre of mean metallic surface, the resistance of the element is.

$$R = 78 \text{ (acid} = 1 \text{ part } SO_3 + 10 \text{ parts } HO.)$$

By using an acid containing 1 part sulphuric acid to 5 of water, the resistance for the unit of surface can be reduced to $R = 30$. This resistance is due to the earthen cells ; for Stöhrer's cells the resistance would be about one-third; therefore—

$$R = 26\ (1\ SO_3 + 10\ HO.)$$
$$R = 10\ (1\ SO_3 + 5\ HO.)$$

Daniell's battery is, perhaps, the most constant of all, which is due partly to the acid being used up less rapidly; since the acid, set free by the decomposition of the sulphate of copper, passes in part at least through the porous cell to the liquid in which the zinc is immersed.

Ryhiner (Dingler's Journal, vol. 110, p. 418) proposes to substitute iron for zinc, and to place it in a solution of common salt. The advantage of this combination is not clearly seen. Its electro-motive force is certainly less than that of the ordinary Daniell's battery.

Ryhiner says of his battery: Though it has not a strong influence on the magnetic needle, it has, nevertheless, a greater reducing effect on metallic solutions than the ordinary zinc battery! (?)

Mr. Ryhiner appears not to know that the chemical effect of a current is always proportional to its magnetic effect.

Moreover, he proposes to substitute linen cells for clay cells, which is quite practicable. One is often in fact embarrassed to get clay cells. Those made by the potter are bad; good ones cannot be had everywhere; and this is the more annoying because the best cells are the most fragile. Ryhiner's cells are made in the following way:

A bag, without ends, is formed of stout twilled linen cloth, and stretched over a tin cylinder; on this, three or four plies of stout paper are fastened with flour paste, and the whole covered with a piece of thin linen. The bottom is made of a flat wooden cylinder, with a groove on its edge, to which the linen is tied fast with twine. The tin cylinder is replaced and filled with hot sand. When all is thoroughly dried, melted wax or rosin is poured in, to stop the cracks in the bottom. The upper edge is soaked in amber varnish.

Whether these cells are really to be recommended, I am unable to decide from my own experience.

§ 18. *Grove's battery.*—According to my measurements, given in section 9—which, however, for Grove's battery, have no claim to great accuracy—the electro-motive force of this battery is, in chemical measures, 829.

Other observers have determined its force, not in an absolute measure, but compared with that of Daniell's battery. Making the electro-motive force of the latter equal to 1, we have for Grove's as follows:

By Jacobi	1.666
By Buff	1.712
By Poggendorff	1.668
By ......do	1.565
Mean	1.653

Assuming the force of Daniell's battery in chemical measure, according to my determination, equal to 470, we should have, in the same measure, that of Grove's equal to

$$470 \times 1.653 = 777;$$

while I found the value of the electro-motive force of this battery to be 829, or about 6½ per cent. greater.

The observers above named made no comparison of the resistance of Grove's battery with that of Daniell's. Such a comparison, however, can hold good only for an individual battery, since it changes with the nature of the earthen cells, and is dependent upon the degree of concentration of the liquid.

A comparison of the resistance of these two batteries is of value only when earthen cells of the same size are used for both, and the same liquid for the zinc cells; while the copper cell of Daniell's battery should contain a concentrated solution of sulphate of copper, the platinum plate of Grove's should be in strong nitric acid. I have not made such a comparison for the Grove's battery, but I have for the zinc and carbon battery, the resistance of which under otherwise like circumstances may be considered equal to that of Grove's. Thus we will return to the comparison of resistance in the zinc and carbon battery.

The proposition has been made to substitute for the nitric acid another substance also containing much oxygen, namely: a solution of bichromate of potash. With this liquid, Poggendorff found the electro-motive force of Grove's battery equal to—

0.987″,

that of Daniell's battery being equal to 1; thus considerably less than with nitric acid. Hence, bichromate of potash is not to be recommended for Grove's battery.

In the 106th volume of Dingler's Polytechnic Journal, page 154, it is stated, that in using Grove's battery for telegraphic purposes, it often happens that the nitric acid penetrates through the earthen cells, and attacks the zinc so powerfully that it has to be newly amalgamated every day. Crystals of Glauber salts cast into the dilute sulphuric acid are said to remedy this evil. The explanation of this may probably be that the Glauber salts are decomposed, and nitrate of soda is formed, the free nitric acid then disappearing.

§19. *Bunsen's battery.*—As a mean of all my experiments, stated in section 9, the electro-motive force of the zinc and carbon battery was found to have, in chemical measure, the value—

824.

The force of Daniell's battery being made equal to 1, that of the zinc and carbon battery was found by

Buff to be	1.712
Poggendorff	1.548

Expressed in chemical measure the force of the battery, according to

Buff, is 805

which accords nearly with my mean; and according to

Poggendorff is 727

The electro-motive force of the zinc and carbon battery, and that of Grove's, are so nearly equal, that in practical use the little difference may be disregarded.

According to Poggendorff, the electro-motive force of Bunsen's battery remains almost the same, if for the nitric acid is substituted a solution of bichromate of potash; indeed, with the liquid it is somewhat greater, the proportion being 1,580 to 1,548.

According to the statements made in section 9, with like mean surfaces, similar clay cells and equally dilute sulphuric acid, the resistance to conduction of the zinc and carbon battery is to that of Daniell's, as—

43 to 78;

or as—

1 to 1.8.

Stöhrer, of Leipsic, has recently considerably improved the Bunsen battery, and made it more convenient for use. His carbon cylinders are steeped in coal-tar instead of sugar-water, and are then brought to a red heat. They are far more solid and have a much smoother surface, which gives them the advantage of absorbing much less nitric acid, which before rendered the use of this battery particularly unpleasant and expensive.

In the first zinc and carbon batteries the copper or zinc ring, which embraced the upper edge of the carbon cylinder, was generally movable. Stōhrer has rendered this fixed. A strip of brass wire is wound about the edge of the carbon cylinder, and a copper ring is screwed in this as firmly as possible. The whole of the upper part is then coated with a solution of shellac. A wire, about one inch long, is fixed to the copper ring, serving as a connexion with the next zinc cylinder. A kind of wire cord, coated with gutta percha, is fastened to the zinc cylinder, and terminates in a binding screw, which can be attached to the copper wire of the following carbon cylinder.

§ 20. *Zinc and iron battery.*—It has been proposed by many to use iron instead of platinum or copper in the construction of galvanic batteries. Roberts made a zinc and iron battery in the following manner. A cast-iron vessel, ten inches high and 3.9 inches in diameter, served for holding a mixture of one part concentrated sulphuric acid and three parts of strong nitric acid; in this liquid an earthen cell filled with dilute sulphuric acid was placed, which cell also served for the reception of the zinc cylinder 9.9 inches high and 3.3 inches wide.

Five such elements yielded forty cubic inches of detonating gas in a voltametre placed in the circuit. This is certainly quite a considerable effect. (Dingler's Journal, vol. 84, p. 386.)

In the same volume of this Journal, p. 385, Schönbein describes a zinc and iron battery which also produced very considerable effects.

Roberts proposed a battery of this kind, with one liquid, for blasting rock. (Dingler's Journal, vol. 87, p. 104; Mechanics' Magazine, 1842.) 20 iron plates and 20 zinc plates, each having 7 square inches of surface, are properly connected and so placed in a frame of slats, that they may be immersed in a trough containing a mixture of 1 part sulphuric acid to 10 parts water.

Callan constructed a zinc and iron battery, (Dingler's Journal, vol. 109, p. 432; Philos. Mag., July, 1848, p. 49,) of a form similar to that which Grove had originally given to his zinc and platinum battery, viz: rectangular smooth earthen cells, 4½ inches long and 4½ high.

A turkey-cock was instantly killed by the stroke of such a battery, composed of 620 elements; and, on examination, the craw was found burst.

Callan says this battery acts fifteen times as strong as one of Wollaston's of the same size, and 1½ as strong as an equally large Grove's battery. This estimate seems exceedingly loose; no facts, no measurements are given, from which the constants of this battery can be computed, even approximately; without this knowledge a correct valuation of a galvanic combination cannot be made.

Measurements of the zinc and iron battery may be found in the 81st volume of Dingler's Journal, p. 273.

Poggendorff found for the electro-motive force of different combinations the following values:

Zinc and platinum	100
Zinc and iron	78.6
Zinc and steel	87.0
Zinc and cast-iron	89.6

The zinc being in dilute sulphuric acid, and the platinum, iron, &c., in concentrated nitric acid. The resistances are tolerably equal in all these combinations.

§ 21. *The iron and iron battery.*—That instead of the platinum in Grove's battery, iron can be successfully substituted, is owing, no doubt, to the fact that iron immersed in concentrated nitric acid becomes passive, and in this state acts like a strong electro-negative metal. From this Wöhler and Weber inferred that iron, placed in concentrated nitric acid, might act towards iron in dilute sulphuric acid as platinum does towards zinc. Their expectation was entirely confirmed on trial, and they constructed a very powerful battery in this manner.

They found it advantageous to use ordinary tin-plate iron for the metal immersed in the dilute sulphuric acid.

Schönbein, also, by his researches on the passivity of this metal, was led to the construction of a battery of passive and active iron. (Dingler's Journal, vol. 84, p. 385.)

The most convenient form of the iron battery is perhaps the following: A cast-iron vessel receives the nitric acid and the earthen cell, in which the dilute sulphuric acid is placed with the active iron.

The rusting of the part of the iron vessel extending beyond the liquid acts injuriously on the working of the battery.

§ 22. *Callan's zinc and lead battery.*—In the Philos. Mag. for 1847, (sec. III, vol. XXXI, p. 81,) Callan describes a new voltaic combination, of which Poggendorff gave an account in volume LXXII of his Ann., page 495. For the platinum of Grove's battery is here substistituted platinised lead, which is immersed in a mixture of four parts concentrated sulphuric acid, two parts nitric acid, and two parts of a saturated solution of nitrate of potash. The zinc is in dilute sulphuric acid, separated of course from the other liquids by an earthen cell.

The action of this battery, according to Callan's account, is not inferior to that of Grove's.

Poggendorff found that in fact the electro-motive force of this combination was equal to that of Grove's; and that the current from it for many hours indicated the same constancy as that of a zinc and platinum battery. But, on the other hand, he found the addition of saltpetre to the nitric acid no improvement, but the addition of concentrated sulphuric acid has the advantage of protecting the lead from the action of nitric acid, which the pulverulent coating of platina cannot do, and allows, besides, the use of dilute nitric acid.

Considered strictly, this combination is a zinc and platinum battery, since the lead serves properly only as a support for the thin film of platinum; therefore zinc and platinum are the terminations of the metallic circuit immersed in the liquid.

§ 23. *The most convenient combination of a given number of voltaic elements for obtaining the greatest effect with a given closing circuit.*—Theoretically, this subject has long since been settled, but the investigations are mostly conducted by the aid of the higher calculus, and the whole is presented in such a form, that the practical use of the proposition is indicated rather than fully exhibited; on this account, a somewhat more detailed exposition may here be in place.

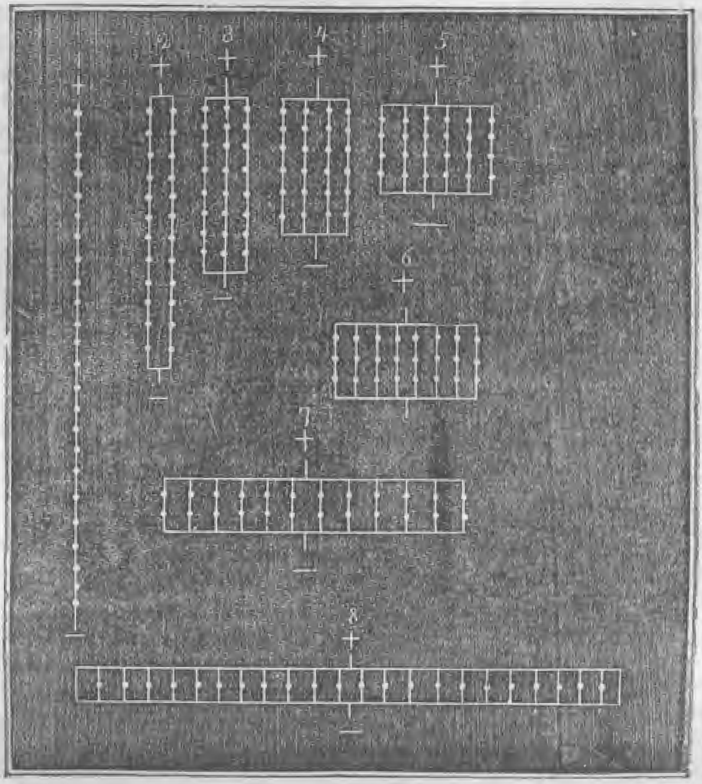
Generally, the question is stated thus: How should a given metallic surface, which is to be used in constructing voltaic elements, be arranged (that is, how many elements and how large should they be,) in order that a maximum effect shall be obtained with a given closing circuit?

This form of the question does not correspond exactly with practical cases. We are not required generally to construct the voltaic battery for a given closing circuit; but the question is, how to combine a disposable number of galvanic elements to obtain a maximum effect.

A maximum strength of current may be obtained from a given number of elements, if they be so arranged, that the resistance in the battery is equal to the resistance in the closing arc.

I will first explain this proposition, then prove it. A given number of elements can be combined in the most varied manner. For instance, 24 elements can be arranged in 8 different ways, as rendered apparent in Fig. 14.

Fig. 14.



1. As a battery of 24 single elements.
2. ....do......... 12 double elements.
3. ....do......... 8 treble elements.
4. ....do......... 6 four-fold elements.
5. ....do......... 4 six-fold elements.
6. ....do......... 3 eight-fold elements.
7. ....do......... 2 twelve-fold elements.
8. ....do......... 1 twenty-four-fold elements.

Which one of these combinations should be selected in a given case, depends upon the resistance to conduction of the circuit. That combination must be taken the resistance of which is nearest to that of the given circuit. Denoting by 1 the resistance of an element, the resistance of the—

1st combination is 24.
2d ....do........ 6.
3d ....do........ 2.666
4th ....do........ 1.5

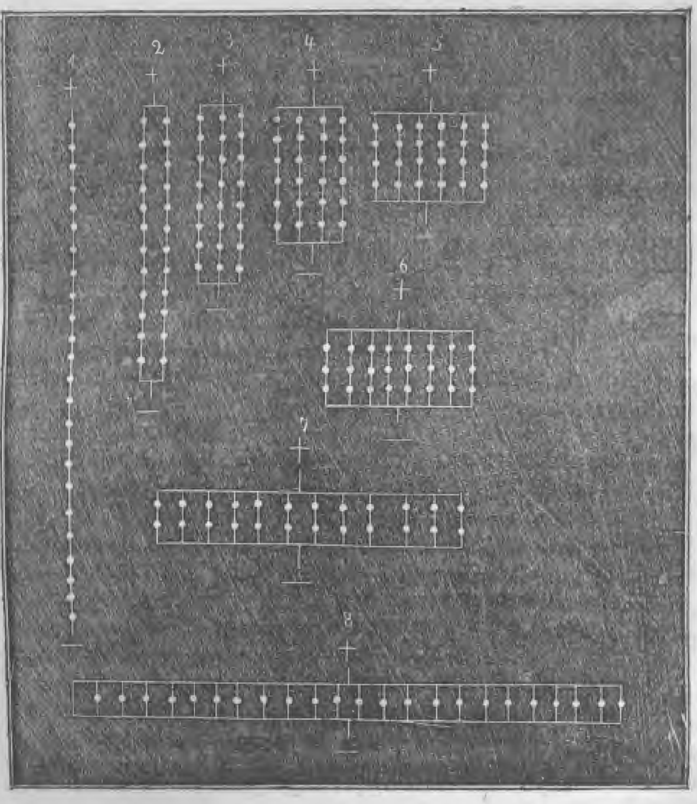
5th combination is	0.666
6th ....do........	0.375
7th ....do........	0.166
8th ....do........	0.046

If the resistance of the given circuit is less than 0.1 of the resistance of an element, the least combination must be selected; but if greater than that of 15 elements, the first must be chosen. If the resistance to be overcome lies between 15 and 4.3, between 4.3 and 2, between 2 and 1.08, &c., the selection must fall upon the 2d, 3d, 4th, &c., combinations respectively.

We have yet to prove the foregoing proposition.

Considering the different combinations of 24 elements, as represented in Fig. 14, it is easily seen that if the pile be shortened, it becomes broad in the same proportion; that is, if fewer elements be placed one after the other, we can, by using the same number of elements, place more of them beside each other, in the same proportion.

Fig. 15.



Commencing with the second combination, we have here 12 double elements. If we reduce the length of the pile by one-half, or to 6., we can double the width of each element—we shall then have 6 fourfold elements.

Making the pile three times shorter, three times as many single elements can be united in one; from 12 double elements we obtain 4 of six-fold. In short, if the pile be made a times shorter, we can unite a times as many single elements in one.

If the number of elements combined, one after another, to form a pile, is a times less, the electro-motive force thus becomes a times less; if the battery had now been made only a times shorter, without increasing its width, the resistance would have been a times less; but if each element of those in a pile consists of a times as many single elements as before, the resistance becomes a^2 times less than before.

Thus the resistance of 6 quadruple elements (combination No. 4) is 4 times less than for 12 double elements, (combination No. 2;) for 4 six-fold elements (combination No. 5) 9 times less than for 12 double, &c.

From this exposition the proof in question is easily derived. For any combination of a number of elements, let the electro-motive force be E, and the battery resistance l. This battery being closed by a conducting circuit, whose resistance is also l, we have, according to Ohm's law, the strength of the current—

$$S = \frac{E}{l + l} = \frac{E}{2\,l}. \qquad (1)$$

The pile being now made a times shorter, but the single elements a times wider, the electro-motive force will be a times less, or $\frac{E}{a}$; but the resistance of the battery will be $\frac{l}{a^2}$, and the force of the current, for the same connecting arc, will be

$$S' = \frac{\frac{E}{a}}{\frac{l}{a^2} + l} = \frac{E}{l\left(a + \frac{1}{a}\right)} \qquad (2)$$

But the sum $a + \frac{1}{a}$ is, under all circumstances, greater than 2*, which, in an integral or fractional quantity we may substitute for a; thus the value of the fraction (2) is, under all circumstances, less than that of (1.) Since (1) denotes the value of the strength of the current for cases in which the resistance in the electrometer is equal to the resistance of the closing arc, and the fraction (2) the value of the strength of current for cases in which the number of single elements is combined in any other manner, the proposition in question is therefore proved.

The application of this proposition may be shown by an example. If, in magnetizing an electro-magnet, the current of 24 zinc and carbon elements be used, the resistance of one element, with weak acid, is 15.05. But resistance of the coils of the electro-magnet has been found *equal to that of* 13.54 *metres of normal wire,* and therefore the resistance of the connecting arc is 0.9 of that of a single element. A glance at the arrangements (Figs. 14 and 15) shows us that we must select the fifth combination as the most suitable; because its resistance, 0.65, is nearer to that of the closing arc, than that of the other combinations. Make, for sake of brevity, the electro-motive force of the element equal 1, and the resistance also 1, then, if we apply successively all of the eight combinations tc the electro-magnet above mentioned, the following values will be obtained for the strength of the current:

1 $\dfrac{24}{24 + 0,9} = 0.963$

2 $\dfrac{12}{6 + 0,9} = 1.74$

3 $\dfrac{8}{2.666 + 0,9} = 2.24$

4 $\dfrac{6}{1.5 + 0,9} = 2.5$

5 $\dfrac{4}{0.666 + 0,9} = 2.54$

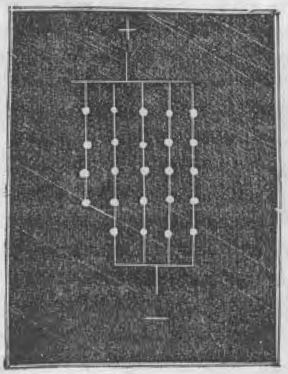
6 $\dfrac{3}{0.375 + 0,9} = 336$

7 $\dfrac{2}{0.166 + 0,9} = 1.85$

8 $\dfrac{1}{0.042 + 0,9} = 1.61$

It is observed here that with the combination 5 the coils of the electro-magnet remaining unchanged, the magnetism of the soft iron will be greater than with any of the other combinations. Combination 4 approaches 5 very closely in its effects; thus the exact maximum should be looked for between 4 and 5. In fact the combination represented in fig. 16 gives the strength of the current 2.56.

Fig. 16.



By charging the same elements with strong acid, the resistance of the element will be 5.85; the resistance of the closing arc will be 2.3 times as great as that of one element, and for this case the third combination (eight three-fold elements) will be the most suitable.

The best combination for a given apparatus to decompose water will be further considered hereafter.

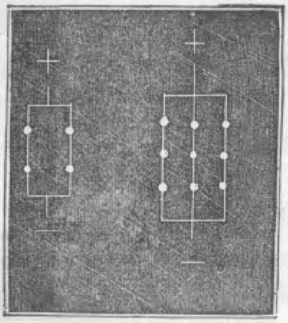
If a given number of elements be so combined that they will yield in a given circuit a maximum strength of current, an increase of the number of elements will increase the strength of the current in the most favorable cases only in proportion to the square root of the number of elements; then 4, 9, or 16 times as many elements must be used to obtain 2, 3, or 4 fold effects.

We shall endeavor to prove this, in a special case. Let the resistance of the closing arc be r, equal to the resistance of one element, the electro-motive force of which is denoted by E, then the strength of the current is

$$S = \frac{E}{r + r} = \frac{E}{2r}$$

Now let us double the force of the current by increasing the number of elements. To obtain a maximum effect from the new combination, the resistance in the battery must continue as great as the resistance of the closing arc; therefore, the resistance of the new combination must not be greater than that of a single element; hence, we shall obtain double the force of the current if, with unchanged resistance, we double the electro-motive force. This is done by placing one element after another; but we must take 2 double elements, if their resistance is to be as great as that of a single element; hence, the combination of Fig. 16 will give twice as great a force of current, and Fig. 17 three times as great, as a single element.

Fig. 17.



To consider this matter in a more general way, let a number of cups a be so combined, that the resistance of the battery is equal to that of the conducting circuit, so that we attain the maximum effect which the number a of cups can produce in the given closing arc. Place 2, 3, . . . n times as many cups together, so that each element of the battery may have 2, 3, . . . n as great a surface; but if the battery is made at the same time 2, 3, . . . n times as long, by placing 2, 3, . . . n times as many elements in succession, then we shall have in all, 4, 9, . . . n^2 times as many cups in use. The resistance of the battery by this arrangement remains unchanged, and therefore the strength of the current increases in the same ratio as the electro-motive force, namely, in the ratio of the number of successive elements; it has thus become 2, 3, . . . n times greater. With $4a$, $9a$, ... $n^2 a$ cups we can, in the most favorable case, obtain 2, 3, ... n times as great a strength of current as that that which can be produced with a elements.

§ 24. *The most suitable arrangement of the closing arc for obtaining a maximum effect with a given electro-motor.*—In some cases the electro-motor is given, and the question is, how the coils of wire must be selected to obtain a maximum effect; from the same quantity of copper are many coils of a thin and long wire to be made, or fewer coils with short and thick wires? In the case of multipliers, the quantity of copper wire to be used is limited by the space which can be conveniently filled by the coils; in that of the electro-magnets the quantity of copper wire is limited by the amount of money to be expended in its construction.

Suppose the resistance of a copper wire of a given length and thickness, making n coils, to be equal to l, or the resistance of the electromotor; then the force of the current is

$$S = \frac{E}{l + l} = \frac{E}{2\,l};$$

and this acting in n coils on the magnetic needles in soft iron, we can represent its effect by

$$M = n\,\frac{E}{2\,l} \qquad (1)$$

If we make the wire m times as long, the mass remaining the same, its section will be m times less, and then the resistance m^2 times greater; hence the force of the current is now

$$S' = \frac{E}{l + m_2\,l} = \frac{E}{l\,(1 + m^2)};$$

but of this length of wire, m times as many coils can be made as before; thus, the magnetic effect is now

$$M' = m.\,n.\,\frac{E}{l(m^2 + 1)} = n\,\frac{E}{l\left(m + \frac{1}{m}\right)}. \qquad (2)$$

But the value of M, as just proved, is always greater than the value of M′. *Hence with a given mass of wire, a maximum of magnetic effect is obtained by giving to the wire such a thickness and length that the resistance in the coils is equal to that of the elements.*

For instance, if we have eight pounds of copper wire for constructing an electro-magnet, to be excited by one of Daniell's elements, described in section 9, how thick must the wire be made?

The resistance of this element is equal to the resistance of 11.1 metres of the normal wire. The normal wire has a section of 0.785 of a square millimetre, or 0.00785 of a square centimetre; thus, a length of 11.1 metres or 1,110 centimetres has a cubic contents of 8.71 cubic centimetres. The specific weight of the copper to be drawn to wire is 8.88; hence the weight of the normal wire, which has the same resistance to conduction as the element, is $8.71 \times 8.88 = 77.34$ grammes.

But the mass of wire which we have at our disposal does not weigh 77.34 grammes, but eight pounds, or 4,000 grammes; so that we have $\frac{4000}{77.34} = 51.7$ times as great a mass as that of the normal wire which fulfils the condition.

If, instead of a wire of given diameter and length, one of three times the diameter be taken, its section is $3 \times 3 = 9$ times greater, and a nine-fold length must be given to it, that it may retain its resistance to conduction unchanged; the volume of the wire is now $81 = 3^4$ times as great as it was before. A wire n times as thick must have a length n^2 as great, and consequently n^4 greater mass, if its resistance is to remain unchanged.

Hence, with a mass p times as great, the wire must have a length $\sqrt{p}$ times as great, and a diameter $\sqrt[4]{p}$ times; the resistance remaining invariable.

The mass of copper to be disposed of is 51.7 times as great as that of a normal wire which offers the same resistance as the elements; hence, we must make of this mass, a wire which is $\sqrt{51.7} = 7.18$ times as long, and $\sqrt[4]{51.7} = 2.68$ times as thick as the normal wire, 11.1 metres long. Thus, if the eight pounds of copper wire is to oppose the same resistance as the Daniell's element, it must be 2.68 millimetres thick, thus requiring a length of $7.18 \times 11.1 = 79.7$ metres.

If the electro-magnet is to be arranged for a Stöhrer's element, whose essential resistance is equal to that of 6.2 metres of the normal wire, for the same reason, the eight pounds of copper must be a wire 3.1 millimetres thick; which requires a length of 60 metres.

Using the electro-magnet constructed for Daniell's battery, with this battery, the strength of the current is

$$\frac{E}{11.1 + 11.1} \text{ or } \frac{E}{22.2.}$$

The wire being placed in n coils about the iron, the magnetic effect may be denoted by

$$M = n \frac{E}{22.2.}$$

Had the wire been twice as long, and consequently one-half in section, its resistance would have been four times as great, or 44.4, and the strength of the current

$$\frac{E}{11.1 + 44.4} \text{ or } \frac{E}{55.5};$$

but this is passed around the iron in 2 n coils, and the magnetic effect is now

$$M' = 2\,n \frac{E}{55.5} = n \frac{E}{27.7}$$

If a wire half as long but double in section had been used, the magnetic effect would have been

$$M'' = \tfrac{1}{2}\,n \frac{E}{13.9} = n \frac{E}{27.8}$$

Thus it is seen that the values of M′ and M″ are less than that of M.

According to these principles, we can also determine how, with a given thermo-electric battery, a multiplier of the greatest possible sensibility may be constructed—a question which was solved theoretically long since, but until now the solution has not had a form susceptible of practical application. On this account we shall give this subject some further consideration.

For instance, our physical cabinet possesses a *thermo-electric pile* with the *galvanometer* belonging to it. I found the

Resistance of the thermo-pile......... =18.34 met. of normal wire.
" " wire of multiplier...... = 1.75 " "

Thus the resistance of the wire of the multiplier is less than one-tenth that of the pile.

Denoting the electro-motive force of the thermo-pile by E, the strength of the current is

$$S = \frac{E}{18.34 + 1.75} = \frac{E}{20};$$

this is conveyed around the needle in n coils; hence the magnetic effect is

$$M = n \frac{E}{20}.$$

If the same mass had been drawn out into three times the length, its resistance would have been 9 times as great, or $9 \times 1.75 = 15.75$, thus nearly equal to that of the thermo-pile. The strength of the current now would be

$$S' = \frac{E}{18.3 + 17.75} = \frac{E}{36};$$

and the magnetic effect

$$M' = 3\,n \frac{E}{36} = n \frac{E}{12};$$

because the current is now conveyed in 3 n coils around the needle. The value M′ is thus nearly double that of M.

With the same quantity of copper wire, the multiplier for the said thermo-pile could have been made twice as sensitive by drawing the wire to thrice the length, so as to give it three times as many coils with a section of only one-third.

Hence there is no doubt that the reason for making the wire of this multiplier too short and too thick, arose from the assumption that the resistance of the thermo-pile composed of a number of metals could not be great, and thus only a wire tolerably thick and not too long should be selected. It is thus shown that mere conjecture will not suffice in such matters.

§ 25. *Comparison of the effects of different batteries in given cases.*—The strength of the current for any given case can be computed from the constants of different batteries. If the resistance of the closing arc is l, for a zinc and carbon battery with a mean surface of one square decimetre, and using Stöhrer cells with dilute sulphuric acid, the strength of current is

$$S = \frac{824}{12 + l}.$$

For a Daniells element, of the same size, with sulphuric acid of the same degree of dilution, the force of the current would be

$$\frac{470}{12 \times 1.8 + l} = \frac{470}{21.6 + 1}.$$

If l is very small compared with the resistance of the elements, the strength of their currents will be to each other as $\frac{824}{12}$ to $\frac{470}{21.6}$, or as 68.6 to 21.8; hence the current of the zinc and carbon battery is more than three times as strong as the other. When the current is well closed, a zinc and carbon element will effect as much as a Daniells element of three times as great a mean surface.

When the resistance is very great, the ratio is different; then the strength of the current is proportional to the electro-motive force, or as 470 to 824. In this case, by increasing the surface of the zinc and copper element, but little would be gained. Two Daniell's elements would have to be united to obtain the same effect as with one zinc and carbon element.

The effect of a zinc and carbon battery can be attained in all cases with a Daniells battery by giving to single elements of the latter a three-fold surface, and using twice as many of them as would be required of zinc and carbon elements.

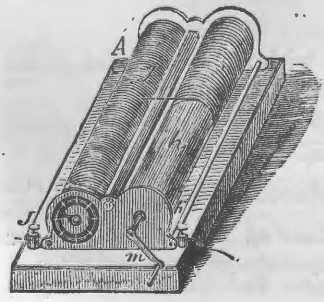
What has been said of the zinc and carbon battery holds good for Grove's battery, since the constants are nearly the same in both.

As a conclusion of this section we present the description of a few instruments which have been used for measuring, in the course of the previous experiments.

§ 26. *Rheostats.*—To accomplish a gradual change of the resistance in the closing circuit of an electro-motor within the desired limit, without being obliged to open the circuit, several instruments have been proposed, chiefly by Jacobi and Wheatstone. Jacobi called his instrument *agometer*. The descriptions are to be found in Poggendorff's Annalen, LIV 340, and LIX 145. An instrument of this kind is very costly, and therefore will not be generally employed, especially since Wheatstone's instruments, constructed for the same object, besides answering the purpose equally well, are far simpler and more convenient in manipulation. In my treatise on physics (Lehrbuch der Physik 3 te., aufl. 2 ter. Bd., S. 193) I have described Wheatstone's rheostat with thick wire, which is to be used when the resistance of the closing conductor is not very great. But when the entire resistance in the battery is very considerable, a great length of this thick wire would have to be wound or unwound to produce a sensible change in the strength of the current; consequently, in such cases a rheostat with a thin wire must be used, and which, of course, must have a different construction.

Wheatstone's rheostat with thin wire is represented in Fig. 18. *g* is a cylinder of dry wood about 6 inches long and 1½ in diameter; *h* is a cylinder of brass having the same dimensions. The axes of the two cylinders are parallel. A screw-thread is cut in the wooden cylinder, and at its end (the one seen in the figure) there is a brass ring to which the end of a long and very fine wire is fastened. This is so wound upon the wooden cylinder as to fill all the screw-threads, and its other extremity is then fastened to the opposite end of the brass cylinder. The small brass columns J and *k*, designed for clamping the wires,

Fig. 18.



rest upon metal springs, one of which presses against the front end of the brass cylinder *h*, the other against the brass ring of the wooden cylinder, (the springs are not shown in the figure.) The winch *m*, which can be removed, serves for turning the cylinder about its axis. Placing it on the cylinder *h*, and turning to the right, the wire is unwound from the wooden cylinder and wound upon the brass one; on the other hand, placing it upon *g*, and turning to the left, the reverse takes place. Since the coils are insulated on the wooden cylinder, and kept apart by the screw-thread, the current traverses the wire throughout its whole length on this cylinder; but on the brass cylinder, where the coils are not insulated, the current passes at once from the point where the wire touches the cylinder to the spring at *k*. The resisting part of the length of the wire is therefore the variable portion which may happen to be on the wooden cylinder.

There are forty screw-threads of the wooden cylinder to an inch. The wire is of brass, and 0.01 of an inch in diameter.

For counting the number of coils unwound, a scale is placed between the two cylinders, and the fraction of a turn is estimated by an index fastened on the axis of one of the cylinders, and which points to the divisions of a graduated circle.

§ 27. *Differential measurer of resistance.*—For determining the resistance of metallic wires, Wheatstone has given a very simple process. The rheostat is inserted in the conducting arc of a constant element with the galvanometer and the wire whose resistance is to be determined, and the whole resistance is so regulated that the needle can come to rest at any desired point *a* of the graduated circle. Now, removing the wire from the circuit, the needle will indicate a greater deflection, and to bring it back to the point *a*, a definite number of turns of the rheostat must be added to the existing resistance. We find in this manner how great the resistance of the wire in question is, expressed in turns of the rheostat.

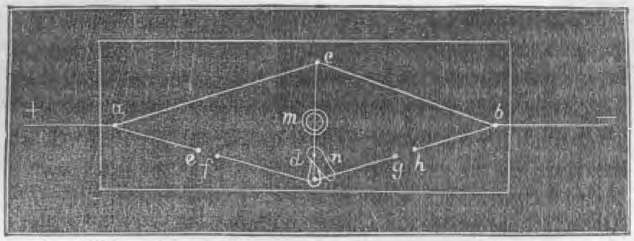
By this method nearly equally accurate results are obtained, whether a multiplier, the much less sensitive tangent compass, or any other galvanometer, be used. The reason is as follows: To produce in a tangent compass a deflection of, say 45°, the entire resistance of the closing conductor must not be very great. Suppose R is the entire resistance of the whole battery, and an increase or decrease *r* of this resistance produces such a change in the strength of the current that the deflection of the needle is varied by 1°.

Now, by using a multiplier, which is about 150 times more sensitive than the tangent compass, the entire resistance of the battery must be about 150 R to cause a deflection of the needle of 45°.

To produce a like change in the strength of the current as that above mentioned, the resistance must now be increased or decreased by 150 *r*. But, since the multiplier is 150 times more sensitive than the tangent compass, the 150th part of this change of resistance, or *r*, will suffice to advance or bring back the position of the needle by 1°; thus the same change of resistance *r* produces in both instruments nearly equal changes of deflection.

If the multiplier is required to indicate very minute changes in the closing conductor, care must be taken that the corresponding difference of current shall act in the multiplier, without a very considerable resistance being inserted in the conductor. Wheatstone has accomplished this by means of the contrivance represented in Fig. 19, which he calls a *differential measurer of resistance.*

Fig. 19.

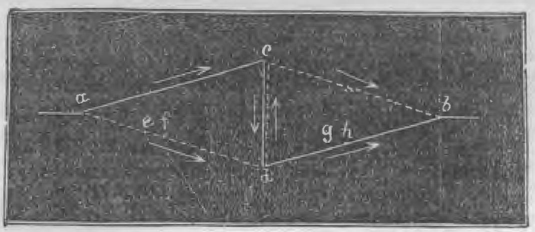


On a board about 14 inches by 4 wide, the small brass knobs *a*, *b*, *c*, and *d* are fastened, forming a paralellogram, and between *a* and *d* are placed *e* and *f*, and *g*, *h* between *d* and *b*. These knobs, which are furnished with binding-screws, are connected by wires, as seen in the figure.

One of the wires of the pole of the electro-motor is screwed in *a*, the other in *b*; the ends of the wires of the multiplier are fastened in *c* and *d*, so that the knobs *c* and *d* are in conducting connexion through the multiplier *m*; between *e* and *f* a piece of wire is inserted, and another between *g* and *h*. The currents here diverge in various branches; but we have to consider only those which pass through the multiplier.

A current passes from *a* to *c*, from *c* through *m* to *d*, from *d* past *g* and *h* to *b*, as indicated by the unbroken line in Fig. 20; another

Fig. 20.



current, which traverses the multiplier in the opposite direction, goes from *a*, through *e* and *f*, to *d*; from *d*, through *m*, to *c*, and finally from *c* to *b*, as shown by the dotted line in Fig. 106. If the resistances in the two conducting wires *a*, *c*, *d*, *b*, and *a*, *d*, *c*, *b*, are perfectly equal, so are also the two currents passing through the multiplier equal; consequently the needle will remain at rest at the zero point.

Now, by making the wire, inserted between *e* and *f*, only a little longer or shorter, the two currents going in opposite directions through the multiplier will be no longer equal, and the difference of strength of the currents will deflect the needle. But since the sum of all the resistances is not great here, a very minute change in the resistance inserted between *e* and *f* will cause a sensible change in the strength of the current, and therefore a sensible deflection of the needle.

Now, to obtain by this contrivance the resistance of a wire expressed in turns of the rheostat, the following method can be adopted: Insert between *e* and *f* a few of the turns of the rheostat, and between *g* and *h* a wire, whose resistance is nearly equal to that of the inserted part of the rheostat on the other side, and adjust everything so that the needle may come to rest at O*. Now, inserting between *g* and *h*, besides the wire already there, the wire whose resistance is to be determined, there must be inserted on the other side a series of *n* turns of the rheostat to bring the needle back again to O. This number *n* of revolutions of the rheostat wire is the measure of the resistance of the wire in question.

Wheatstone has constructed other instruments besides this for the same object; but the description of this, the simplest one, will suffice.

SECTION THIRD.

RESISTANCE OF METALS AND LIQUIDS, GALVANIC POLARIZATION AND PASSIVITY.

§ 28. In order to compute by Ohm's formula the strength of current in a given case, it is not sufficient to know merely the constants of the electro-motor—we must also know the resistance of the solid conductors which are inserted in the closing circuit; and in case the current has to traverse a decomposing cell, besides the resistance of the liquids, we must also know the electro-motive opposing force appearing at the electrodes, or what is called the galvanic polarization. The conduction of the current, it is well known, depends upon the dimensions of the body, and also on its specific conductive capacity, which we shall now consider.

§ 29. *Resistance of metals.*—Buff has determined the resistance of a few of the metals by Wheatstone's method, as follows (Jahresbericht von Liebig und Kopp für 1847 and 1848, s. 286:)

Silver	0.954
Copper, (chemically pure,)	1.000
Copper of commerce, first quality	1.170
Do second quality	1.507
German silver	11.833

He has taken the resistance of silver as unity; but since all resistances have been compared here with copper, I have reduced the data of Buff to this metal.

To distinguish the absolute value of resistance of a wire from these proportional numbers, I propose to call them *the specific resistance to conduction.* The specific resistance to conduction of a metal is the

---

[*] To facilitate such an arrangement Wheatstone has introduced a special contrivance into his instrument. The knob *d* rests firmly upon a piece of brass. At the other end of this strip of brass another piece *n* turns about a pin, its free end resting on the wire. When *n* lies on *d* it has no effect, but the further it is turned from *d* towards *g* the more will the resistance on the course *d g* be reduced. If necessary the movable piece of brass *n* can also be brought to the other side of *d*.

number which denotes how many times its resistance is greater than that of a copper wire of equal dimensions. Representing by s the specific resistance of a metal, the absolute resistance w of a wire with a length l and a radius r, is

$$w = s \frac{l.\,0.785}{\pi\, r^2}$$

Specific resistance is what Riess terms *electrical retarding force;* hitherto the reciprocal value of specific resistance has been indicated by the term *capacity for conduction.* But in practice it seems advisable to use the numerical value of specific resistance instead of capacity for conduction.

The values found by Buff for specific resistance of silver, copper, and German silver, given above, deserve entire confidence, because they were determined with great care, and by, what is important, a *simple and direct method,* which is susceptible of the greatest accuracy. The silver was prepared specially for this object in the chemical laboratory at Giessen. The copper was prepared with great care by the galvanic process, but was not entirely free from iron, as analysis showed that it contained 0.02 per cent. of that metal. The first quality of commercial copper contained 0.22 per cent. of iron ; the second quality, besides a trace of iron, 0.2 per cent. of lead, and 0.26 per cent. of nickel.

In the following table the resistances of different metals, as determined by E. Becquerel, (Ann. de chimie et de phys. 3 serie XVII, 242 ; Pog. Ann. LXX, 243,) are compared with those found by Riess, the specific resistance of copper being taken as unity :

	Riess.	Becquerel.		Frick and Müller.
		Hard.	Annealed.	
Silver	0.67	0.95	0.89	
Copper	1.00	1.00	0.97	1
Gold	1.13	1.38	1.36	
Cadmium	2.61	3.62		
Brass	3.61			4
Zinc		3.69		
Palladium	5.49	6.63		
Iron	5.66	7.44	7.30	6.4
Platinum	6.44	11.08	10.99	
Tin	6.80	6.52		
Nickel	7.69			
Lead	9.70	10.86		
German silver	11.29			13.3
Mercury		49.49		

The method by which Becquerel obtained these numbers is essentially as follows : His galvanometer, which he terms a differential galvanometer, is formed of two equal but separate wires placed side by side, each three metres long. The ends of the two coils of the multiplier are now so joined to the electro-motor that the current takes opposite directions in them, so that only the difference of strength of the two currents comes into play. In one of the closing conductors the rheostat is inserted, by means of which the resistance in both circuits can be made perfectly equal, so that the galvanometer needle remains at zero. Now, if in the other circuit we insert the wire to be determined, then to retain the needle at zero, the resistance of an equivalent number of rheostat coils must be added to the existing resistance. In this way the resistance of the wire is first expressed in rheostat coils.

It is easily seen that this method is practically the same as that by Wheatstone's differential resistance-measurer, which, however, has the great advantage that with it any ordinary galvanometer can be used, while Becquerel's method requires one of peculiar construction.

The silver which Becquerel used in his experiments was reduced from the chloride, and the copper was precipitated electro-chemically and melted.

The numbers of the last column are computed from experiments which Frick and myself made conjointly by Wheatstone's method. The copper was from galvanic precipitation.

Most of the experiments gave for silver a resistance very near to that of copper, while Riess and Lenz before him found it considerably less. This great difference cannot depend upon the want of purity in the silver, for that would increase rather than diminish the resistance.

According to the measurements of Lenz (Pog. Ann. XLIV, 345) the resistance of

Antimony is............11.23
Mercury is...............21.45
Bismuth is 38.47

§ 30. *Dependence of the resistance of metals on temperature.*—Lenz has investigated the influence of change of temperature on the conductive capacity of metals. His reports may be found in Poggendorff's Annalen, Bd. XXXIV, p. 418, and Bd. XLV, p. 105. We extract from the last-named paper the following results:

	Conductive capacity for electricity at—		
	0°.	100°.	200°.
Silver	136. 25	94. 45	68. 72
Copper	100. 00	73. 00	54. 82
Gold	79. 79	65. 20	54. 49
Tin	30. 84	20. 44	14. 78
Brass	29. 33	24. 78	21. 45
Iron	17. 74	10. 87	7. 00
Lead	14. 62	9. 61	6. 76
Platinum	14. 16	10. 93	9. 00

It is very evident from this table how great the influence of heat is on the conductive capacity of metals, and also how unequal this influence is in the different metals. For instance, at 100° the last five metals have entirely changed their respective positions in the order o conductive capacity: lead has become the worst conducting metal; platinum has gone above iron; brass conducts better than tin, which, at 0°, is above it. At 200° the series is relatively the same as at 100°, though here copper and gold have become nearly equal; so that gold, at a yet higher temperature, must be a better conductor than copper.

In reference to the method by which Lenz arrived at the above results, we have a few remarks to make. The current which he used was magneto-electrical, in the closing circuit of which a multiplier was inserted alternately with and without the wire to be determined. This wire was coiled spirally, yet so that the single coils did not touch, and it was plunged in an oil bath, kept at a constant temperature by a spirit-lamp. The conductive capacity of the wire was now determined for a series (mostly 10 to 15) of different temperatures of the oil bath, and then by means of the different relative values of the conductive capacity g and the temperature t, the probable values of the constant factors of the equation,

$$g = a + bt + ct^2,$$

were found. In this manner the following equations for computing the conductive capacity of different metals were obtained:

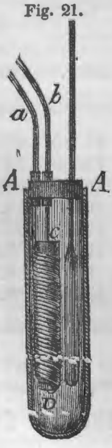
For Silver........................ $g = 136.25 - 0.4984\,t + 0.000804\,t^2$
Copper........................ $g = 100.00 - 0.3137\,t + 0.000437\,t^2$
Gold........................ $g = 79.79 - 0.1703\,t + 0.000244\,t^2$
Tin........................ $g = 30.84 - 0.1277\,t + 0.000273\,t^2$
Brass........................ $g = 29.33 - 0.0517\,t + 0.000061\,t^2$
Iron........................ $g = 17.74 - 0.0837\,t + 0.000150\,t^2$
Lead........................ $g = 14.62 - 0.0608\,t + 0.000107\,t^2$
Platinum........................ $g = 14.16 - 0.0389\,t + 0.000066\,t^2$

These formulas, by which the above table was computed, accord very well with the observations.

E. Becquerel has also investigated the relation of the conductive capacity of metals to temperature.

The method by which Becquerel maintained his wires at a high temperature is as follows: The metallic wire to be used in the experiments is wound on a glass tube C D, Fig. 21, one centimetre in diameter and five or six centimetres in length, so that the single coils do not touch each other. If the wire should be more than one layer, it must be covered with silk, and then the second layer of coils wound on the tube. To prevent the coils from unrolling, they are fastened with silk. Both ends of the wire are now fastened to the lower ends of the thick copper rods a b, whose resistance may be disregarded. One of the rods, namely, a, is fastened to the upper end of the glass tube C D; the other, b, passes down into the tube. The coil, with its wrappings, is now placed in a test tube filled with oil. The two rods a and b pass through two small openings made in the cork A A′, which holds C D in the middle of the oil. A thermometer with a long bulb serves for taking the temperature of the oil.

Fig. 21.



The oil was heated by immersing the test tube in a water bath; hence Becquerel's measurements did not exceed the boiling point of water.

Becquerel infers from his observations *that the decrease of conductive capacity is proportional to the increase of temperature.*

Consequently, the resistance of a metal increases by an equal amount for each degree of temperature. The following table indicates the amount of increase of resistance for one degree expressed in fractions of the resistance at zero.

Silver	0.0040	Platinum	0.0019
Lead	0.0043	Zinc	0.0037
Gold	0.0034	Cadmium	0.0040
Iron	0.0047	Tin	0.0062
Copper	0.0041	Mercury	0.0010

From this Becquerel computed a table for the conductive capacity of these metals at 0° and 100°, in which, however, the conductive capacity of silver at 0° is made equal to 100; to compare these data with those of Lenz, I have re-computed the table, making copper = 100.

Metal.	At 0°	100°	Difference.
Silver	109.3	77.9	31.4
Copper	100.0	70.9	29.1
Gold	71.0	52.6	18.4
Cadmium	26.8	19.1	7.7
Zinc	26.2	19.2	7.0
Tin	15.3	9.4	5.9
Iron	13.5	9.2	4.3
Lead	9.0	6.3	2.7
Platinum	8.6	7.3	1.3
Mercury	1.9	1.7	0.2

It is evident that there is not the least accordance here with the results of Lenz, either in regard to the conductive capacity of the metal at 0°, or in regard to the decrease of the same with increasing temperatures. If the law found by Becquerel were correct, the factors of t^2 in the equations on the last page should be zero, and the factors of t multiplied by 100 should be equal to the differences of the above table.

Finally, Müller, of Halle, has investigated this subject (Pog. Ann. LXXIII, 434) with the view of showing that a relation exists between the increase of the specific resistance to conduction, and the increase of specific heat. He assumed the measurements of Lenz with reference to resistance; for verifying those numbers he instituted a series of experiments himself with iron wire, the results of which accorded well with those of Lenz. The increase which the resistance of zinc and mercury underwent at increasing temperatures, and which Lenz had not determined, Müller found to be very nearly proportional to the increase of temperature.

With reference to specific heat at different temperatures, Müller adopted the determinations of Dulong and Petit, with the assumption that the increase of specific heat is proportional to the increase of the rise of temperature. Whether this be true or not we shall not attempt to decide; but if it were the case, the converse would be proved, of what Müller desires; for, according to the determinations of Lenz, the increase of resistance to conduction is *not* proportional to the increase of temperature; the hypothesis of Müller would, perhaps, accord better with the measurements of Becquerel.

Müller now compared the increase of the specific heat of mercury, platinum, copper, zinc, silver, and iron, with the corresponding increase of resistance; the accordance is not remarkable. This, however, in Müller's opinion, does not militate against his assumption of the dependence of the increase of resistance on the specific heat, because the determinations of specific heat at different temperatures have not been carried to the requisite degree of accuracy. If this want of accuracy be admitted, as in fact it must be, we must also admit that to try to prove such a relation with our present knowedge of facts is, to say the least, a fruitless endeavor.

§ 31. *Resistance of the human body to conduction.*—Lenz and Ptschelnikoff have investigated this subject, and made use of a magneto-electrical spiral as an electro-motor. According to their determinations, the resistance of the human body, the whole hand being immersed in water with the addition of $\frac{1}{100}$ part of sulphuric acid, is equal to that of

$$91762$$

metres of copper wire 1 millimetre in diameter. This can be considered as only a rude approximation, consequently the description of the details of the experiment is not necessary.

Pouillet previously (P. A. XLII, 305) estimated the resistance of the body at

$$49082$$

metres of standard wire.

Although these numbers may be very inaccurate, they nevertheless show us that the resistance of the body is very great, and that, therefore, the strength of the currents which produce physiological effects is always very feeble.

Suppose a human body introduced into the closing circuit of a Bunsen's battery of 50 cups, the strength of the current will be

$$\frac{50 \times 800}{49000} = \frac{40}{49} = 0.8$$

by assuming the electro-motive force of a Bunsen element to be in round numbers = 800, and the resistance of the battery (about 500) being disregarded when compared with that of the body, provided we take for the resistance of the body the smaller number of Pouillet. This force of current corresponds to a deflection of about $\frac{3}{4}$ of a degree of our tangent compass. A single Bunsen element closed by the body would thus give a force of current of only

$$\frac{0.8}{50} = 0.016$$

Is the induced current arising from a single element, though it produces in the human body such powerful shocks, any more considerable?

§ 32. *Galvanic polarization.*—A piece of wire of the length of 2, 3, 4, opposes to the galvanic current a resistance 2, 3, 4; the electro-motive force of the battery and its resistance being known, the strength of current can be computed from Ohm's law for any wire inserted. Denote by E the electro-motive force of the battery, by R the resistance of the battery, then if r denotes the resistance of the closing conductor, the strength of current is

$$S = \frac{E}{R + r}$$

and if a wire of equal thickness, but n times as long as the closing wire, be used, the strength of current is

$$S' = \frac{E}{R + n r}$$

This is not the case with the insertion of liquids. Denote by E and R the same as above, and by w the resistance of the liquid in a voltameter, which is inserted in the circuit, then

$$S = \frac{E}{R + w}$$

would be the strength of current, if Ohm's law applied here as to the metallic wires. By separating the plates of the voltameter n times as far apart, the strength of the current must be

$$S' = \frac{E}{R + n w}$$

If the strength of the current has been determined for a certain distance of the voltameter plates, it will be found for double, treble, or four times that distance of the polar plates—greater than should have been expected from the immediate use of Ohm's formula.

This may be seen from a series of experiments made by Lenz, and which were communicated in volume XLIV of Poggendorff's Annalen, p. 349. Without going further into the description of the method of observation employed by Lenz, it will suffice here to present some of the results obtained.

With metallic closing in his battery, (the current being magneto-electric,) Lenz obtained a strength of current = 0.648, (according to an arbitrary unit.) When the current passed through a concentrated solution of sulphate of copper, in which two copper plates were immersed as electrodes, the force of current was found

0.425,

where the electrodes were 12.6 millimetres apart. Denoting the whole resistance which the current had to overcome in the first case, by 1, we have

$$\frac{E}{1} = E = 0.648.$$

And if the resistance of the inserted liquid be computed in exactly the same manner as that of the wire, we should get

$$\frac{E}{1 + x} = 0.425, \text{ hence } x = 0.5.$$

If the electrodes were removed 8 times as far apart, other things remaining the same, we should expect, if Ohm's law could be applied without further trouble, that the stratum of liquid 8 times as thick would oppose a resistance 8 times as great, and that the force of the current should now be

$$\frac{E}{1 + 8\,x} = \frac{0.648}{1 + 8 \times 0.5} = \frac{0.648}{5} = 0.129.$$

But experiment gave in this case the force 0.199.

At 12 times the distance apart of the pole plates, we should expect, from the application of Ohm's law, that the current would be 0.0648, while experiment gave 0.120.

In somewhat different form a similar result was obtained from the experiments of Horsford, (Pog. Ann. LXX, p. 238.) In the circuit of a Bunsen battery, he inserted a tangent compass and a rheostat. By means of the latter the deflection of the needle was brought back to 10°. A stratum of dilute sulphuric acid 2.5 centimetres thick, between two platinum plates, was now inserted, and with this 32 coils were taken from the rheostat, or, in other words, 32 coils were removed from the circuit to bring the deflection again to 10°. When the two plates were placed twice as far apart, it was not necessary to remove 32 coils from the circuit to bring the needle to rest at 10°, but only 20.5 coils. For each increase in thickness of the fluid strata, of 2.5 millimetres, only 20.5 coils had to be removed from the circuit to obtain the same deflection.

Thus it appears, from all experiments of the kind, that the diminution of the strength of the current, which is produced by inserting a decomposing cell in the conducting circuit of a battery, does not depend entirely upon the proper resistance of the liquid, but that there is another cause at work diminishing the current, which, however, is not augmented by the thickness of the stratum, but apparently is independent of it.

Fechner ascribes this to the so-called "resistance to transition," which acts at the surface of contact between the metal plates and liquid. Thus he imagines that the current has to overcome, besides the resistance of the fluid itself, a peculiar resistance at the pole plates of the decomposing cells, which we will denote by u. If, with a given thickness of the liquid stratum, the strength of current is

$$S = \frac{E}{R + u + w}, \tag{1}$$

then for a stratum n times as thick, the strength of the current, according to Fechner's view, will be

$$S' = \frac{E}{R + u + n\,w}. \tag{2}$$

Poggendorff at first defended this hypothesis of Fechner. Lenz has shown, in the paper cited above, that the strength of the current which passes through a liquid may be calculated by formula, (2), and believes he has thus proved the existence of resistance to transition.

Ohm, Vorselman de Heer, and other physicists, opposed this hypothesis, and ascribed the above mentioned anomalies to a *galvanic polarization* of the voltameter plates, which acts in opposition to the electro-motive force of the battery. Denoting this force by E, the strength of current, after inserting a voltameter, would be, according to this view,

$$S = \frac{E - e}{R + w}; \tag{3}$$

e donating the electro-motive opposing force in the voltameter, the other letters retaining their former signification.

At n times the distance of the plates from each other, the strength, according to this view, would be

$$S' = \frac{E - e}{R + nw}. \tag{4}$$

Lenz treats of this subject again in volume LIX of Poggendorff's Annalen, p. 229. A new series of experiments on the strength of the currents with inserted voltameters is compared with formulas (1) and (3); and Lenz finds that both satisfy the observations, and that the changes in the strength of currents produced by the voltameter can be made to accord with Ohm's law, as well by the hypothesis of a resistance to transition as by that of an electro-motive opposing force at the electrodes.

Thus this investigation of Lenz leaves the question undecided, while he himself holds the opinion that galvanic polarization is more probable than resistance to transition.

From the form in which Lenz combined his experiments, no decision could be expected; but, with another mode of considering this subject, this would not have been the case. We need only determine the simple electro-motive force of a battery once with metallic circuit, and then, with the voltameter inserted, to find whether or not an electro-motive opposing force appears in the voltameter.

A series of experiments, which I made for the purpose of rendering the solution of the question apparent, gave the following results:

Six zinc and carbon elements formed the battery. The tangent compass inserted in the circuit gave

For insertion of 0	46° deflection.
For insertion of 49 metres of standard wire	30 "

Consequently the value of the electro-motive force of the battery is

$$E = 4366.$$

A similar experiment, in which a brass wire was inserted, equal to 29.2 metres of the standard wire, gave

$$E = 4479;$$

then the mean is

$$E = 4422.$$

A voltameter was then inserted. Without any further addition, the deflection was

$$31^\circ.8.$$

When an iron wire, whose resistance was equal to 49 metres of the standard wire, was inserted in addition, the deflection was

$$20^\circ.6\,;$$

consequently

$$E' = 3320.$$

After exchanging this iron wire for the above mentioned brass wire, (= 29.2 metres of standard wire,) the result was

$$E = 3520,$$

and the mean

$$E' = 3420.$$

These experiments show clearly that the electro-motive force is diminished by inserting the voltameter, and diminished not a little; for we have

$$e = E - E' = 1000.$$

Hence, if a decomposing cell be introduced in the circuit, two causes come into action diminishing the strength of the current—first, the electro-motive force, which sets the current in motion, is diminished; and second, the resistance is increased. The strength of the current in this case is to be computed by the formula

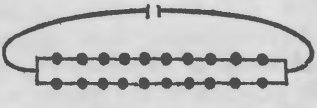
$$S = \frac{E - e}{R + w}.$$

Daniell was the first, to my knowledge, who proved the existence of galvanic polarization, simply by using Ohm's law, (Philos. Trans., 1842, Pt. II, Pogg. Ann., LX, 387,) and he did it in a very ingenious way, without using any other instrument than the voltameter itself.

An instrument of this kind was inserted in the closing arc of a battery of 5 Daniell elements, as shown in Fig. 22; 6 cubic inches of detonating gas were evolved in 5 minutes. If there was no electromotive opposing force present, the same voltameter, placed in the closing arc of 10 double elements, should yield double the quantity of gas in the same time; for in the first case the strength of the current was

Fig. 22.

Fig. 23.



$$\frac{5\,E}{5\,R + r^1}\,;$$

in the second,

$$\frac{10\,E}{\frac{10}{2}\,R + r} = \frac{10\,E}{5\,R + r'}\,;$$

hence in the last case we should obtain 12 cubic inches of gas in five minutes. The experiment, however, did not give 12, but 20 cubic inches. Making the electro-motive opposing force equal e, we have in the first case

$$\frac{5\,\mathrm{E} - e}{5\,\mathrm{R} + r} = 6\,;$$

in the second,

$$\frac{10\,\mathrm{E} - e}{5\,\mathrm{R} + r} = 20\,;$$

therefore,

$$\frac{10\,\mathrm{E} - e}{5\,\mathrm{E} - e} = \frac{20}{6}\,;$$

hence,

$$e = 2\,857\,\mathrm{E}\,.$$

Thus the experiment proved not merely the existence of the electro-motive opposing force, but also determined its magnitude.

§ 33. *Resistance of liquids to conduction.*—To determine the proper resistance of liquids we must take the influence of galvanic polarization into consideration; ignorance or disregard of this was the reason why all former experiments for determining the specific resistance of liquids yielded entirely contradictory results.

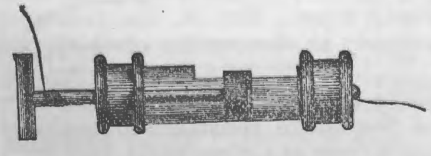
Lenz first sought to determine the specific resistance of a solution of sulphate of copper, free from the influence of polarization, and found the value

$$6857\,500\,;$$

that is, a solution of sulphate of copper, in the form of a liquid pile, terminated by metal plates at both ends, being inserted in the closing arc of a battery, opposed to the galvanic current a resistance 6857 500 times greater than a copper rod of the same dimensions, (Pog. Ann. XLIV, 349.)

Wheatstone proposed an excellent method for determining the resistance of liquids independent of polarization. A glass tube two inches long, and about one-half inch in interior diameter, (Fig. 24) has one-fourth of its circumference ground away, leaving a large part of its length open above; at one end of the tube a metal stopper is fastened, terminating in a platinum plate; at the other end a movable piston, ending also in a platinum plate, can be brought within one-fourth of an inch of the fixed plate, and removed from it to the distance of five-fourths of an inch.

Fig. 24.

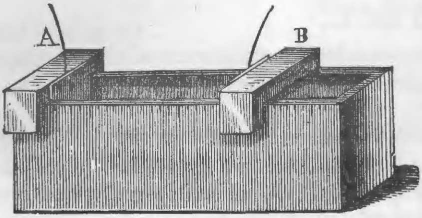


To determine the resistance of a liquid, this measuring tube is inserted with the galvanometer and rheostat, in the closing arc of a constant battery of about three cups. When the two platinum plates of the tube are one-fourth of an inch apart, the interval is filled with the liquid whose resistance is to be measured, and then by means of the rheostat the deflection of the needle of the multiplier is brought to a given point. The piston is now drawn back one inch, and the interval filled again with the liquid; of course the needle has receded, and to restore it to its original position, the resistance of the battery is diminished by aid of the rheostat and resistance rolls,* until the needle comes to rest at its first position. The reduced length of the wire thus brought from the battery is the measure of the resistance of one inch of liquid; the influence of polarization has already been eliminated by the method of the experiment.

The arrangements which Horsford and Becquerel used, to measure the resistance of liquids, are founded on the same principle.

Horsford used a quadrangular trough of solid wood (Pog. Ann. LXX, 238) 3 decimetres in length and 7½ centimetres in breadth and depth, for holding the liquid, (Fig. 25;) the inside is coated with shellac varnish to prevent the escape of the liquid. Two pieces of wood are placed on the trough; one of which, A, is fastened, while the other, B, can be moved back and forth as a slide. These cross-pieces serve for holding the immersed plates in the liquid, and for changing their distance apart at pleasure. The plates, the same width as the trough, are fastened to copper strips, which are again screwed to the cross-pieces.

Fig. 25.



The trough, filled with the liquid, is now placed with the rheostat and tangent compass in the closing arc of a battery of more or less cups, according as the circumstances require a greater or less electromotive force. The course of the experiment is similar to that indicated by Wheatstone.

Horsford's arrangement has many advantages. 1. The measurements can be extended by placing the plates at a greater number of distances apart; 2. Plates of different metals can be easily substituted; and 3. Experiments can be made with the trough filled to different heights.

Horsford has shown that liquid columns follow exactly the same law in regard to resistance as metallic wires; that is, the resistance is directly as the length, and inversely as the section of the liquid stratum.

The trough being filled with dilute sulphuric acid, the plates were placed 2.5 centimetres apart, and the entire resistance so regulated that the needle of the compass came to rest at a given point, (say 20°.)

The second column of the following table indicates the number of rheostat coils (of German silver wire) which were removed from the circuit to restore the compass needle to the same place, when the distance apart of the plates (the trough being kept filled to the same

---

* If the requisite changes of resistance exceed the limits of the rheostat, the object is accomplished by the insertion or removal of wire rolls (thin wire wound between the fine screw-thread of a dry wooden cylinder) the resistance of which is known. By adding or taking away such resistance rolls the greater changes of resistance are accomplished, and the smaller ones are produced by the rheostat alone.

height, namely, 2.75 centimetres) was increased by the values in the first column:

Distance of plates, centimetres.	Coils removed.
2.5	2.11
5.0	4.25
7.5	6.98
12.5	10.75
25.0	20.67

Since the corresponding numbers of the two columns here have nearly the same ratio throughout, the resistance of the fluid column is thus actually proportional to its length. In the mean we get from this experiment, for the resistance of a stratum of liquid of five centimetres, the value 4.3 rheostat coils.

When the trough was filled to a height of 4.8 centimetres, the value 2.56 rheostat coils was obtained from a similar experimental series for the resistance of a liquid column five centimetres long of the same dilute acid.

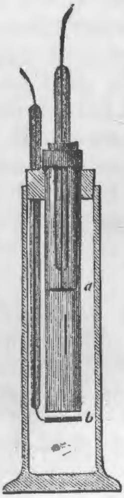
Now, since the heights of the liquid in the trough, 2.75 and 4.8, are nearly in inverse proportion to the corresponding resistance 4.3 and 2.56, (namely, 2.75 : 4.8 = 2.56 : 4.46,) the resistance of the liquid column is in inverse ratio of its section.

The following table contains the values determined by Horsford, for the specific resistance of different liquids:

Name of liquid.	Condition.	Specific resistance, that of silver = 1.
Sulphuric acid	Specific gravity 1.10	938,500
Do.	do 1.15	840.500
Do.	do 1.20	696,700
Do.	do 1.24	696,700
Do.	do 1.30	696,700
Do.	do 1.40	1,023,400
Solution of chloride of sodium	27.6 grains in 500 cc. water	7,157,000
Do.	21.3 do do.	9,542,000
Do.	10.65 do do.	18,460,000
Do.	5.325 do do.	34,110,000
Solution of chloride of potassium	27.7 do do.	7,168,000
Solution of sulphate of copper	Of which 100 cc. contains 15.093 grains	12,058,000
Do.	With double volume water	17,490,000
Solution of sulphate of zinc	Of which 100 cc. contains 7.2587 grains	23,515,000

These liquids were chemically pure.

Fig. 25.



The apparatus represented in Fig. 26 was used by Becquerel for measuring the resistance of liquids (Ann. de chim. et de phys. 3 series, XVII, 242.) Its construction hardly requires any further explanation. The metal plate *a* is movable up and down in a glass tube, at the lower end of which the plate *b* is placed; thus the current has to traverse the liquid column between *a* and *b*. The conducting wires of the plates *a* and *b* are enclosed in glass tubes to prevent lateral currents.

Becquerel applies the differential galvanometer here also; in each of the two closing circuits is inserted an apparatus like that of Fig. 26. In order that he might raise or lower the plate *a* in one of them, he arranged so that the multiplier needle came to rest at 0.

A spiral wire of known resistance having been inserted in one of the closing arcs, the needle deviated and the liquid column of that circuit had to be shortened to restore the needle to 0. In this manner it was found how long the liquid column should be, to exert the same resistance as the inserted spiral wire. It is understood, of course, that there were contrivances for measuring the exact elevation or descent of the plate *a*; but of these, it is not necessary to give the description.

By this method Becquerel found the following values for the specific resistances of different liquids, silver being taken as 1:

Saturated solution of sulphate of copper..........	18,450,000
Do............common salt....................	3,173,000
Do........... nitrate of copper.............	11,120,000
Do...........sulphate of zinc...............	17,330,000
Dilute sulphuric acid (220 c. c. water + 20 c. c. sulphuric acid with 1 atom of water)..........	1,128,000
Commercial nitric acid of 36° B....................	1,606,000

With reference to the influence which the degree of concentration had upon the solution, Becquerel found the following results:

Liquid.	Resistance.
Sulphate of copper, saturated solution	18,450,000
" " diluted to 2 volumes	28,820,000
" " diluted to 4 volumes	48,080,000
Common salt, saturated solution	3,173,000
" diluted to 2 volumes	4,333,000
" diluted to 3 volumes	5,721,004
" diluted to 4 volumes	7,864,000

§ 32*. *Computation of strength of current by means of an inserted voltameter.*—When the resistance of the liquid and the approximate quantity of galvanic polarization are known, it is easy to compute the strength of current of a given combination. Suppose, for example, a voltameter, whose plates have a surface (on each side) of 25 square centimetres (2,500 square millimetres) and are 1 centimetre (0.01 metre) apart, is filled with dilute sulphuric acid of the specific gravity 1.4; then the resistance of the liquid column in the voltameter is—

$$1023400 \frac{0.01 \times 0.785}{2500} = 32;$$

hence the strength of the current is $\frac{E - 1000}{R + 32}$, denoting by E the electro-motive force, and by R the entire resistance of the pile, and assuming for the polarization the approximate value 1,000.

When a voltameter is inserted in the closing arc of a battery, the principle is no longer true, that a maximum strength of current is obtained when the given number of cups are so arranged that the resistance of the battery is equal to the resistance of the closing arc; because the supposition on which the demonstration was based, namely, that in different combinations of the same number of cups the resistances vary in proportion to the square of the electro-motive force, does not hold good here by reason of the polarization in the voltameter. The maximum effect is in favor of those combinations in which more cups stand in a row and fewer beside each other.

That a change of the maximum should take place in this way, may be easily seen from a special example. In the various combinations of 24 cups, of Daniell's elements, (where E = 470, R = 22,) a wire was inserted, whose resistance was equal to 32; the following *forces* of current were obtained for these combinations:

$$1. \quad \frac{24 \times 470}{24 \times 22 + 32} = \frac{11280}{560} = 20.$$

$$2. \quad \frac{12 \times 470}{6 \times 22 + 32} = \frac{5640}{164} = 34.$$

$$3. \quad \frac{8 \times 470}{2.7 \times 22 + 32} = \frac{3670}{91} = 41.$$

$$4. \quad \frac{6 \times 470}{1.5 \times 22 + 32} = \frac{2820}{65} = 43.$$

$$5. \quad \frac{4 \times 470}{0.7 \times 22 + 32} = \frac{1880}{47} = 40.$$

$$6. \quad \frac{3 \times 470}{0.4 \times 22 + 32} + \frac{1410}{41} = 34.$$

Hence, we have the maximum, 43, for the case where the resistance of the battery, 1.5 × 22 = 33, is nearly equal to that of the closing arc. But, by inserting the above-mentioned voltameter, whose resistance is 32, instead of the metallic wire of the same resistance, the strength of current must be less, because the numerator of the above fraction has to be reduced by 1,000; hence we get the following strengths of currents for the different combinations:

1. $\frac{11280}{560} - \frac{1000}{560} = 20 - 2 = 18.$

2. $\frac{5640}{164} - \frac{1000}{164} = 34 - 6 = 28.$

3. $\frac{3760}{91} - \frac{1000}{91} = 41 - 11 = 30.$

4. $\frac{2820}{65} - \frac{1000}{65} = 43 - 15 = 28.$

5. $\frac{1880}{47} - \frac{1000}{47} = 40 - 21 = 19.$

6. $\frac{1410}{41} - \frac{1000}{41} = 34 - 24 = 10.$

Thus, in fact, the maximum effect is changed from the fourth to the third combination.

We see, from these results, that among the ratios here considered, the diminution of strength of current, by polarization, is less for those combinations for which the entire resistance is greater, and therefore the change of maximum, in the way indicated, is explained.

We have supposed here that the amount of polarization is constant; but this is not the case, as we shall see subsequently. The final result of this consideration, however, will not be changed essentially in consequence of this.

§ 33.* *Diminution of the resistance of liquids by heat.*—While the resistance of metals is increased by heat, that of liquids, on the other hand, is considerably decreased. The first measurement of this was made by Becquerel, (Annales de Chemie et de Phys., 3 Series, XVII, 285.) He used the method above described. One of the vessels, Fig. 26, was heated in a water bath until the temperature became constant.

At the temperature 14°.4 Becquerel found the resistance of a column of saturated solution of sulphate of copper, whose height was 3.88, equal to the resistance of a given platinum wire. But at the temperature 56° the resistance of the same wire was equal to a liquid column 8.50 in height.

Since a rise of temperature of 56° — 14°.4 = 41°.6 is required to increase the conductive capacity of the saturated solution of sulphate of copper in the ratio of 3.88 to 8.50, a rise of temperature of 35° is necessary to double the conductive capacity of this liquid, provided the changes of conductive capacity are proportional to those of temperature. With a rise of temperature of 1° the conductive capacity of this solution will be increased by $\frac{1}{35}$, or 0.0286 of its value at 14°.4.

In the same manner Becquerel found that for a rise of temperature of 1°, the conductive capacities of the following liquids were increased by the following parts of their original values indicated below:

A dilute solution of sulphate of zinc	0.0223
Commercial nitric acid	0.0263

Hankel has published a more extensive series of experiments on this subject, (Pog. Ann., LXIX, 255.) He found the *resistance of a concentrated solution of sulphate of copper* (A) *of the spec. grav.* 1.17, at different temperatures, as follows:

0°	11.26
11.9	7.33
31.0	4.70
66.4	3.12

The resistance of 108.7 *parts of the former solution* (A) *with* 185 *parts was, at*

0°	22.87
11	15.16
25	10.5
67.4	7.1

The resistance of a concentrated solution of nitrate of copper was, at

0°	4.89
11.5	3.27
25	2.18
67.2	1.64

The resistance of a concentrated solution (B) *of sulphate of zinc was, at*

0°	13.05
9.8	8.62
27.4	4.55
67.4	2.29

The resistance of a mixture of 71 *parts of the solution* (B) *and* 116 *parts water was, at*

0°	13.00
11.1	8.82
28.8	5.57
65.1	3.51

The unit to which these resistances were referred was arbitrary.

The construction of the vessel holding the liquids used in these experiments cannot be clearly understood from Hankel's description.

On considering the result, we find that the decrease of resistance is not proportional to the increase of temperature, as Becquerel supposes.

For the concentrated solution of sulphate of copper, we have on an average the following for a rise of one degree of temperature:

Limits of temperature.	Decrease of resistance.
0° and 12°	0.327
12 " 31	0.138
31 " 66.4	0.044

Thus for a given difference of temperature, the corresponding change in the resistance of the liquids is greater, the lower the temperature.

§ 34. *Galvanic polarization varies with the magnitude of the force of the current.*—Many physicists, and among others Lenz, (Pog. Ann., LIX, 234,) have expressed the opinion that the electro-motive opposing force of a voltameter is independent of the strength of the current.

In Daniell's memoir, mentioned above, (Pogg. Ann., LX, 387,) this opinion is adopted, and the attempt is made to establish it by a series of experiments with the voltameter. These measurements, however, are not exact enough for this purpose. Wheatstone also entertains this opinion, and is thereby led to a further false conclusion. He determined the electro-motive force of a battery of three Daniell's elements, then the electro-motive opposing force in a voltameter, which was inserted in the closing arc of the same battery. He found

$$E = 90 \quad e = 69.$$

When batteries of four, five, and six elements were used, almost exactly the same value for e was found; hence Wheatstone inferred that the electro-motive opposing force may be considered as constant. E is here the electro-motive force of three combined cups, consequently the electro-motive force of one cup is $\frac{E}{3} = 30$, a value less than e. Wheatstone thinks that the phenomenon may be explained by supposing that a single element cannot effect the decomposition of water in a voltameter.

But this is erroneous. The electro-motive opposing force can never become stronger than the original cause which produces it; hence we must suppose that the electro-motive oppposing force is dependent upon the strength of the current. But then the current of a single element can certainly decompose water, though at a very small rate. For instance, when a voltameter was inserted in the closing arc of a Daniell's element, its plates being about two square inches, I obtained a very sensible development of gas.

That the electro-motive opposing force in a voltameter actually depends upon the strength of the current, appears very strikingly in a series of experiments which I made for this purpose. As already mentioned above, I found the electro-motive force of a battery of six zinc and carbon elements to be—

$$E = 4422,$$

and the electro-motive opposing force,

$$e = 1000.$$

The electro-motive force of each single element was $\frac{4422}{6} = 737$, thus decidedly less than the electro-motive opposing force in the voltameter.

The electro-motive force of a battery of four such elements (zinc and carbon) was next determined; the result was

$$E = 3124.$$

After inserting the voltameter the electro-motive force was only

$$E^1 = 2427;$$

hence,

$$e = E - E' = 700.$$

Here, with a weaker current, the electro-motive opposing force appeared sensibly less; indeed, in this case it is less than the electromotive force of an element.

For a battery of two elements the result was

$$E = 1604.$$

After the insertion of the voltameter,

$$E' = 984,$$

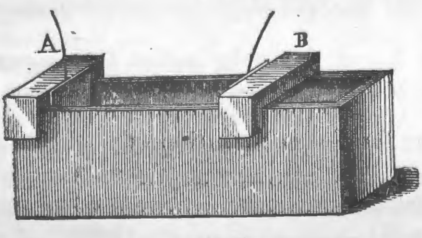
thus—

$$e = E - E' = 620.$$

No claim to great accuracy is made for the numbers just given, but that which is placed beyond doubt by them is what might have been foreseen; the electro-motive opposing force becomes gradually less with the decrease of the strength of the current. Hence it is a function of the current, though the force of this function must be determined by more accurate experiments.

That the magnitude of the electro-motive opposing force is dependent on the strength of the current was first placed beyond doubt by Poggendorff.—(P. A., LXI, 613.) Buff also (P. A., LXIII, 497) found the electro-motive opposing force of a voltameter greater with the current of three zinc and carbon elements than with that of only two; he found, moreover, the magnitude of the polarization diminished by the insertion of a greater length of wire in the closing arc.

Fig. 27.



For the case in which the electrodes fill up the whole section of a trough like that of Fig. 27, the polarization appeared somewhat greater, according to Buff, when the decomposing cell is less full. If the electrodes are suspended in the surrounding liquid, without filling the whole section, the size of the electrodes has no influence on the magnitude of the polarization.

§ 35. *Numerical determination of polarization.*—Lenz and Saweljev have instituted a large series of experiments for determining galvanic polarization in different cases. (Bull, de la Classe Phys. Math. de l'acad. de Sci. de St. Peters, b. T. V., p. 1; P. A., LXVII, 497.) The process which they used to determine the magnitude of polarization in a decomposing cell was that of Wheatstone, viz: by determining the electro-motive force of a battery, first with metallic closing conductors, and afterwards with the decomposing cell inserted. The difference of these two numbers, gives the magnitude of the electromotive opposing force produced by the polarization in the decomposing cell.

The following example will explain the mode of observing.

To reduce the deflection of the compass-needle from 20° to 10° the following must be inserted:

With metallic closing	19.91 rheostat coils.
A decomposing cell being inserted in the closing arc, formed of two plates of platinum immersed in nitric acid	17.37 "
Polarization of the decomposing cells	2.54

By this method the following values were found for the galvanic polarization of different decomposing cells:

Copper-plates in sulphate of copper	0.07
Amalgamated zinc plates in nitric acid	0.03
Copper-plates in nitric acid	0.01

These experiments prove that polarization disappears when the escape of gas ceases at the electrodes; in all three cases no oxygen appeared at the positive electrode, because it oxidized the metal immediately on its evolution from the water; the escape of hydrogen at the negative electrode was prevented in the first case by attracting in its nascent state the oxygen from the oxide of copper, and precipitating metallic copper; in the other two cases the nascent hydrogen was immediately oxidized by the nitric acid.

Thus here, where the electrodes are not covered with a stratum of gas, polarization does not take place; the small numerical values given above are not due to the polarization of the electrodes, but to the fact that they do not remain in the same state—one plate being attacked and the other not, and thus the pair of plates itself becomes a feeble electro-motor.

Buff also (P. A., LXXIII, 497) found the polarization for copper plates in sulphate of copper, and for zinc plates in sulphate of zinc, very small.

Lenz and Saweljev found further for the polarization of

Platinum plates in nitric acid		2.48
Platinum plates in sulphuric acid*		5.46
Amalgamated zinc plates in SO_3		1.00
Copper plates in	"	2.15
Tin electrodes	"	1.45
Iron electrodes	"	0.33
Graphite in concentrated	"	1.26

These numerical values are mostly the mean results of a number of experiments.

In the first case, that of platinum plates in nitric acid, there is no escape of hydrogen at the negative electrode—the polarization shown in the value 2.48 is thus to be ascribed entirely to that at the positive electrode, where oxygen appears; 2.48 is consequently the magnitude of the polarization which a platinum plate receives from oxygen.

In the second case, that of platinum plates in sulphuric acid, development of gas takes place at both electrodes; therefore 5.46 is the

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* Composed of 6 vols. of concentrated SO_3 + 100 of water.

sum of the polarization of both plates; the polarization of platinum by oxygen being 2.48; that of the same metal by hydrogen is 5.46 — 2.48 = 2.98, or nearly 3.

In the four succeeding cases, (zinc, copper, tin, and iron, in sulphuric acid,) the positive electrode is attacked, and therefore the corresponding numerical values are those of the polarization of these metals by hydrogen. Arranging these results, we have for the polarization of

Platinum in oxygen	2.48
Platinum in hydrogen	3.00
Zinc in..........do	1.00
Copper in........do	2.15
Tin in...........do	1.45
Iron in..........do	0.33
Graphite or carbon in oxygen	1.25

If we introduce into the closing circuit of a battery a decomposing cell of unlike plates, this itself will act as an electro-motor, and the effect of its force will, according to circumstances, either favor or oppose the polarization. Suppose the electro-motive force of the decomposing cell, as well as its polarization, to oppose the electro-motive force of the battery, then the difference D obtained from the measurements of the electro-motive force of the battery, with and without the decomposing cell in the circuit, will be the sum of the electro-motive force of the decomposing cell, and of the polarization, or

$$D = e + p;$$

denoting by e the electro-motive force of the decomposing cell, and by p the polarization taking place in it. If we have determined the value of D for differently constructed decomposing cells, (say, for example, consisting of platinum in nitric acid, and zinc in sulphuric acid, platinum in nitric acid, and copper in a potash solution,) we can compute for these combinations the value of e by deducting the respective values of p. In this manner Lenz and Saweljev ascertained the electro-motive force of the following combinations:

Platinum in nitric acid, combined with—

Platinum in hydrochloric acid	0.26
Do......sulphuric acid	0.02
Do......nitric acid	0.00
Graphite in nitric acid	0.01
Gold in nitric acid	0.06
Gold in sulphuric acid	0.25
Mercury in sulphuric acid	0.70
Mercury in nitrate of mercury	0.79
Platinum in solution of potash	1.20
Pure copper in sulphuric acid	1.39
Slightly oxidized copper in sulphuric acid	1.75
Copper in sulphate of copper	2.00
Gold in solution of potash	2.31
Tin in hydrochloric acid	2.38
Iron in......do......do	2.75
Graphite in solution of potash	2.84

Iron in sulphuric acid	2.92
Tin in.......do.......do	2.95
Copper in solution of potash	3.10
Tin in solution of potash	3.94
Zinc in dilute nitric acid	4.05
Zinc in dilute hydrochloric acid	4.07
Zinc in sulphuric acid	4.17
Iron in solution of potash	4.65
Zinc in......do.........do	5.48

For zinc in sulphuric acid, and copper in sulphate of copper, these two Russian physicists found the electro-motive force 2.17. This gives us a point of reference for reducing the numerical values, given above, for polarization and electro-motive force to our (the chemical) unit. We have found for the electro-motive force of a Daniell element the value of 470 (section 9); and to reduce the values given by Lenz and Saweljev to chemical measure they must be multiplied by $\frac{470}{2.17} = 217$.

For the electro-motive force of a Grove's element, (platinum in nitric acid, zinc in sulphuric acid,) they found the electro-motive force 4.17; consequently, in chemical measure, it is $4.17 \times 217 = 905$.

Hence, for the polarization of different metallic plates, we get the following values expressed in chemical measure:

Platinum in oxygen			538
Platinum in hydrogen			651
Zinc	"	"	217
Copper	"	"	466
Tin	"	"	314
Iron	"	"	72
Carbon in oxygen			271

for the entire polarization of the two platinum electrodes in dilute sulphuric acid

1185,

while for this case I found the number (section 32)

1000.

§ 36. *Polarization in platinized platinum plates.*—Poggendorff observed, accidentally, that in an element of the Grove gas column, which was inserted in the closing arc of a Grove element, a considerable development of gas took place unexpectedly, while a simple Grove element, closed by a voltameter with uncoated platinum plates, produced a very inconsiderable decomposition of water. (Pogg. Ann., LXX 183.)

For making comparative measurements, he constructed a voltameter with platinized platinum plates, which he compared with an ordinary voltameter. The voltameter with uncoated plates yielded in the closing arc of a Grove element, in thirty minutes,

0.89 cubic centimetres of explosive gas;

while the voltameter with platinized platinum plates, under the same circumstances, yielded

77.68 cubic centimetres;

thus nearly 87 times as much.

This is due simply to the fact, that the polarization in platinized plates is considerably less than in uncoated plates. Poggendorff has proved this by direct measurements.

The electro-motive force of a battery of two Grove's elements was $= 64$; after inserting the platinized plates it was 31; hence the polarization of the platinized plates was

$$64 - 31 = 33.$$

When, instead of the voltameter with platinized plates, that with uncoated platinum plates was substituted, the electro-motive force of the whole battery was equal to 22; therefore the polarization on the uncoated plate was

$$64 - 22 = 42.$$

It is shown, in section 18, that the electro-motive force of a Grove element, as a mean of the observation of different physicists, is 777 in chemical measure; hence the electro-motive force of two elements equals 1554; therefore the value of the polarization of the uncoated plates which Poggendorff found, reduced to chemical measure, is

$$42 \times \frac{1554}{64} = 1020;$$

which accords very closely with the value of the polarization given above in section 32.

Hence the polarization for platinized plates, in chemical measure, is

$$33 \times \frac{1554}{64} = 801.$$

Poggendorff also found, as mentioned already in section 34, that the magnitude of the polarization diminishes with the strength of the current; when, by the increase of the accidental resistance, the current was so weakened that the needle of the sine compass, inserted in the closing arc, receded from 47° 49′ to 5° 44′, the polarization in the voltameter diminished from 42 to 38, or, in chemical measure, from 1020 to 922.

According to Poggendorff's experiments, the magnitude of the polarization with platinized plates is but little dependent upon the changes of the strength of the current, so that it may be considered constant, without sensible error.

Svanberg also has instituted many experiments in galvanic polarization, and with great care and accuracy. (Pogg. Ann., LXXIII, 298.) For the polarization which the current of four Daniell elements produced in a voltameter with uncoated platinum plates, he found, reduced to chemical measure, the value

1072.

Svanberg observed, that the polarization in the voltameter increases gradually, and requires some time to attain a maximum. Therefore, to determine the maximum polarization accurately, he made his measurements only after the current had been passing for some hours through the voltameter.

Metal plates with rough surfaces appeared from his measurement to be polarized less than polished ones, which accords well with Poggendorff's observation, that the polarization on platinum plates is less than on naked ones. The polarization of polished copper plates by hydrogen, Svanberg found in the ratio of 12 to 8 less when they were made rough with a file, or still better when rendered granular by galvanic precipitated copper.

§ 37. *Buff's researches on galvanic polarization.*—Single results of these researches have been already mentioned above, but we must here present a few more extracts from Buff's Memoir. (Pogg. Ann., LXXIII, 497.)

He found that a deflection of 45 degrees in his tangent compass corresponded to a development of hydrogen of 21.08 cubic centimetres per minute, (reduced to the temperature of 0° and 760 millitres pressure?), which is equivalent to a development of explosive gas of 31.6 centimetres; hence the strength of the current was reduced to chemical measure by multiplying the tangent of the angle of deflection by 31.6.

In the course of this investigation, Buff found the electro-motive force of a Daniell element equal to 4.207. Since, in establishing our unit we have taken the electromotive force of this element at 470, Buff's data of electro-motive force, as well as his value of polarization, must be multiplied by $\frac{470}{4.207} = 111$ to make the results comparable with ours. Buff's comparison of the strength of current and magnitude of polarization in a voltameter with naked platinum plates, (referred to our unit), gave the following results:

Strength of current.	Polarization.
43.7	1256
19.7	1165
11.5	1132
8.0	1118
4.4	1069

In these experiments the platinum electrodes formed the opposite sides of a trough; the above numbers relate to the case where the trough was filled to a height of 45 millimetres.

Filled to a height of 10 millimetres, the following respective values of strength of current and polarization were obtained:

Strength of current.	Polarization.
20.5	1199
11.5	1170

Thus, under circumstances otherwise equal, the polarization appeared somewhat greater than when the trough was filled higher, as already mentioned in section 35.

Buff also remarked that the maximum polarization required a considerable time to elapse before taking place.

For one decomposing cell formed of two zinc plates in a solution of sulphate of zinc, he found the value of polarization,

$$p = 0.85\,;$$

in our unit

$$p = \quad 94.$$

From this result he is led to the following conclusions:

"I regard $p = 0.85$ as the electrical difference of zinc and hydrogen, or as an approximation to it. In like manner I regard the polarization resistance of the platinum plates in dilute sulphuric acid as an approximate value for the electrical difference between oxygen and hydrogen. By the stratum of hydrogen at the negative platinum plate, and the stratum of oxygen at the positive plate, the same effect is produced as though not two platinum strips, but a strip of solid hydrogen and one of solid oxygen, were placed in the acid. * * * The electro-motive action developed by the immediate contact of hydrogen and oxygen, or the electrical difference of these substances, indicates the extreme limits of the resistance, which can take place by the polarization of two metals in the decomposing cell. This limit will be approached the more nearly, the more perfectly the immersed plates can be coated with the gases, and the more perfectly the immediate contact of the metallic with the liquid conductors is prevented."

In the same memoir we find other experiments proving the absence of polarization in all cases, in which the deposition of the gases on the electrodes is prevented, which has been previously mentioned. (Section 35.)

§ 38. *Diminution of polarization by heating the liquid.*—De la Rive describes the following experiment in the *Biblioth. Univers., February*, 1837, *p.* 388: In the closing arc of a battery of four elements, he inserted a galvanometer and a decomposing cell, composed of two platinum plates, immersed in a glass of water; the galvanometer indicated a deflection of 12°. He then placed under the positive pole-plate where oxygen was developed, a large spirit-flame, so that the plate began to glow, and the part immersed in the liquid being gradually heated by conduction, raised it to the boiling point. (The platinum plate was probably bent at right-angles.) No change was perceptible in the deflection; the same was done at the negative plate, but now the needle advanced to 30°. After removing the lamp, the deflection returned to 12°.

When the water was replaced by dilute sulphuric acid, the original deflection was 45°; by heating the negative plate it rose to 80°, while heating the positive plate had no effect whatever.

Hence De la Rive concludes, that heat has no influence on the passage of the electrical current from a metal into a liquid, but that it perceptibly favors the passage of the current from a liquid to a metal.

Vorsselman de Heer opposed this singular opinion. He ascribed the action not directly to heat, but to the motion of the liquid produced by boiling, and by which the polarizing gases were removed from the electrodes. He supported his view by the fact that the same effect can be produced without heat, by merely agitating the plate slightly in the liquid, or causing motion in the liquid near the plates by a glass rod.

He took a voltaic pile of five pairs charged with pure water. Two platinum wires dipped in a glass of distilled water, forming the poles of the battery, the galvanometer placed in the circuit indicated 45°; this deflection, however, rapidly decreased on account of the increasing polarization, but it always increased again when the negative wire was shaken. The following results were obtained:

After 15′	34°;	the negative wire being	shaken,	40°
After 30′	16°;	do.	do.	38°
After 60′	4°;	do.	do.	32°

Shaking the positive wire had no influence.

Similar results were obtained with copper wires.

Vorsselman's explanation is certainly the correct one, yet he leaves unexplained the circumstance of the positive pole being unaffected by heating or shaking. Is it because oxygen adheres more firmly to platinum plates than hydrogen?

According to a notice in the "Jahresbericht über die Fortschritte der Chemie, Physik u. s. w. von Liebig und Kopp, Giessen 1849, s. 297," Becker of Giessen has investigated more minutely the decrease of polarization at increasing temperatures of the decomposing fluid; but his labors have not yet been published.

§ 39. *Cause of galvanic polarization.*—One of the first who opposed the hypothesis of resistance to transition, and endeavored to establish the existence of an electro-motive opposing force in the voltameter, was Schönbein. While all the researches on this subject, hitherto considered, rested upon the relation of the passage of the current through electrolytes, to Ohm's law, and while they were in this way led indirectly to the view that galvanic polarization was to be ascribed to the strata of gas covering the electrodes, Schönbein regarded the subject from an entirely different point of view, and sought to prove directly the polarizing influence of gases on metallic plates.

The most important of Schönbein's memoirs on this subject are the following:

Observations on the electrical polarization of solid and liquid conductors. (Pog. Ann. XLVI, 109.)

New observations on voltaic polarization of solid and liquid conductors. (Pog. Ann. XLVII, 101.)

On voltaic polarization of solid and liquid bodies. (P. A. LVI, 135.)

I will here state the essential results of Schönbein's researches, without reporting upon the contents of these separate papers.

The following experiment is mentioned on page 199 of the second volume of my treatise, (Lehrbuch der Physik.) If the current of a battery be passed through a voltameter, and then, directly after breaking the circuit, each of the voltameter plates be brought into contact with the terminating wire of a multiplier, the latter will indicate a current traversing the voltameter in the direction opposite to that of the original current of the battery. This experiment, made as early as 1827, by De la Rive, merely shows that an electro-motive opposing force is generated in the voltameter by the primary current; but it gives us no clue to the cause.

Becquerel maintained that the secondary current appeared only in the case when the poles were immersed in the solution of a salt. Under these circumstances, says Becquerel, the salt is decomposed, the base collects at the negative pole, the acid at the positive; and if the wires be put in conducting connexion after the removal of the battery, a current is generated in consequence of the re-combination of the acid and base.

Schönbein now shows that a solution of a salt is not at all necessary for bringing about a secondary current; that the experiment succeeds perfectly with pure water very slightly acidified with pure sulphuric acid, even if the platinum electrodes communicates but for an instant with the battery.

These secondary currents are by no means of only momentary duration; they last, according to circumstances, a longer or shorter time. In an instance in which the original deflection of the galvanometer needle by the secondary current amounted to 80°, four minutes elapsed before it altogether disappeared; in another, when the deflection was 160°, it lasted thirty minutes.

Schönbein produced secondary currents as well with electrodes of gold as with those of platinum. Iron wires being used instead of platinum, and a solution of potash for sulphuric acid, the secondary current also appeared. Experiments with silvered copper wire, zinc, and other metals, gave similar results; so that it is in the highest degree probable that all metallic conductors have the property of being electrically polarized.

In the second of the above-mentioned memoirs (P. A. XLVII, 101) Schönbein arrives at an explanation of the phenomenon. The most important facts which lead to it are the following:

1. Platinum wires or plates which, being placed for a greater or less length of time in pure water, or in water with sulphuric or nitric acid, have served as electrodes, and are then heated to redness in a spirit flame, lose entirely all their electro-motive power.

2. If the positively polarized electrode, or that which has served as a negative pole, be exposed but for a few moments to an atmosphere of chlorine or bromine, the electro-motive force will be completely destroyed; the same result is also obtained by a longer immersion in oxygen gas.

3. A negatively polarized platinum wire loses its electro-motive force if it be exposed a few seconds to an atmosphere of hydrogen.

4. By exposing positively or negatively polarized platinum plates to a gas which has no chemical action either on oxygen or hydrogen

in the presence of platinum, the electro-motive force of the plates will not be destroyed.

5. A platinum plate exposed for only a few seconds in an atmosphere of hydrogen, is polarized positively.

6. Gold and silver wire do not acquire electro-motive power by immersion in hydrogen gas.

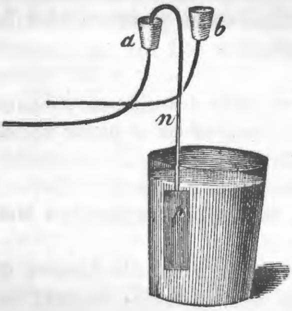
7. A platinum wire placed in oxygen does not become negatively polarized, nor do gold and silver.

8. Platinum, gold and silver, exposed for a few seconds in chlorine gas, become polarized negatively. Bromine gas produces the same effect on these metals.

Before passing to a further elucidation of these facts, we will consider the most advantageous way of showing the electrical polarization of a metallic plate.

In a small cup of mercury *a*, Fig. 28, connected with the terminal wire of a multiplier, the end of a wire of a platinum plate *p* is immersed. The plate must be first perfectly cleaned, and then suspended in a glass of acidified water. In the cup *b* the wire of a second and exactly similar platinum plate is placed—the plate being in like manner cleaned and suspended in the acidified water. The needle will, of course, remain at rest, since both plates act exactly alike electro-motively. But if the second plate, which we will denote by *p'*, should be polarized in any of the above ways, a deflection of the galvanometer needle would follow, from which the direction of the current could be ascertained.

Fig. 28.



For example, if the platinum plate *p'* were immersed in hydrogen gas, it would act electro-positively towards the other; that is, the galvanometer would indicate the current passing from *p'* through the liquid to *p*. The plate *p'* being immersed in chlorine gas, the deflection of the needle would show *p'* electro-negative to *p*.

If the platinum plate *p'* should have served as the negative pole in the decomposition of water, it will act exactly as though it had been plunged into a jar of hydrogen; that is, if used for closing in the apparatus of Fig. 28, it would generate a current passing from *p'* through the liquid to *p*.

All the phenomena we have just considered, appear to indicate that the stratum of gas which escapes at the electrodes during electrolysis is really the cause of galvanic polarization. If such be the case, it is perfectly evident that the stratum of gas will be destroyed by heating the metal plates to redness. This circumstance alone, however, would prove nothing, because such a heat must act destructively upon the polarity, even if it should depend upon other causes than upon a stratum of gas. The second experiment is decisive. The instantaneous destruction of the positive polarity of a platinum wire, by chlorine, can hardly take place otherwise than by the chemical action of the chlorine on the oxygen, by which every trace of hydrogen disappears in the formation of hydrochloric acid. On immersion in oxygen, the hydrogen adhering to the platinum plate is caused by the action of the latter to combine with the oxygen, and thus the cause of the polarization is removed. That oxygen does not destroy the positive polarity so quickly as chlorine, is owing merely to the slow action of the oxygen.

The fact mentioned under No. 4 is also favorable to the view, that the cause of the polar condition of the electrodes exists in the hydrogen and oxygen which adhere to them. The certainty of this supposition is established by the fact stated in No. 5; at least this appears to prove incontestably that the positive polarity of the negative electrode is due to hydrogen.

A platinum wire which has not been used as a negative pole, and has not been subjected in any way to the influence of a current, presented all the voltaic properties of a positively galvanized wire, merely from the fact of having been exposed a few seconds to hydrogen.

Schönbein has, in fact, by these experiments, removed the vail which has hitherto concealed the nature of galvanic polarization.

Only two of the facts stated above, namely, those under 6 and 7, appear to oppose the explanation he has given.

While a platinum plate, which has been used as a positive electrode, is negatively polarized, the polarization cannot be produced by exposure to oxygen; this seems to show that the negative polarity of the positive pole is not to be ascribed to oxygen.

The circumstance that gold and silver wire do not become electro-positive in hydrogen, while the same metals, if they have played the part of negative electrodes but for a few seconds, become sensibly positively polarized, excites some doubt as to the correctness of the view that the positive polarization of the negative electrodes is to be attributed to hydrogen.

But before passing to a closer examination of this subject, we will first consider the polarization of liquids which Schönbein also discusses in the above mentioned memoirs.

§ 40. *Polarization of liquids.*—If dilute hydrochloric or dilute sulphuric acid be placed in a U-shaped tube, and connected a few seconds by platinum electrodes with the poles of a battery, the current of which causes a sensible development of gas in the acidified liquid, and if then the wires thus used be replaced by new ones, or such as have not served as poles, and these wires be connected with the galvanometer, the needle of this instrument will deviate, and in a direction which shows that the positive current of the liquid column in which the negative pole was immersed passes in the direction of that in which the positive electrode was, or, in other words, the secondary current is in the opposite direction to the current of the battery.

Thus liquid columns indicate galvanic polarization.

The cause and nature of this polarization are explained by the following experiments:

1. Water, made conducting by a little sulphuric acid, being agitated with hydrogen and placed in a tube closed below with a bladder, and the tube put in a vessel which also contains some acidified water, but free from hydrogen, and both liquids then connected with the

galvanometer by platinum wires, a current is obtained which passes from the hydrogen solution to the other liquid. The former acts relative to the latter as zinc to copper. When gold or silver wires were used in this experiment, no current was obtained.

2. The experiment having been made under exactly the same circumstances, excepting that the liquid in the tube contained oxygen in solution instead of hydrogen, there was no current with connecting wires of platinum, gold, or silver.

3. When the liquid in the tube contained a small quantity of chlorine or bromine instead of hydrogen, a current was obtained, which passed from the wide vessel into the tube, whether the experiment was made with platinum, gold, or silver wire.

4. If the current of a battery be passed through water containing sulphuric acid placed in a U-shaped tube, this liquid will yield a secondary current only in case the connexion with the galvanometer be made with a platinum wire. By using gold or silver wire the needle of the multiplier does not show the least deflection.

5. If the experiment be made as in 4, using, however, dilute hydrochloric acid instead of dilute sulphuric acid, a secondary current will be obtained even when the closing has been made with gold or silver wire.

The experiments under 1, 3, and 5 indicate that the course of the polarization is to be found in the gases which are dissolved in the water.

The cases in which the liquids treated with gases yield no current from polarization, (Nos. 2 and 4,) exactly correspond with the cases above described, where metallic wires or plates immersed in gases produced no such current, (Nos. 6 and 7.) In order to prove that the stratum of gas adhering to the metallic plates or the gases dissolved in the liquids are the cause of galvanic polarization, it must be explained why the same effect is not also produced in these cases. The view of Schönbein on this subject we give in the following paragraph:

§ 41. *Schönbein's theory of galvanic polarization.*—If two like metallic plates be immersed in a liquid, one clean and the other coated with a stratum of gas; or if two such plates be placed in the two branches of a U-shaped tube filled with the same liquid, except that in the liquid in one of the branches a gas is held in solution, and not in the other, the dissimilarity between the two parts is a sufficient cause for the appearance of electrical tension. This tension will cause an electrical current as soon as a metallic connexion is made between the two plates. But in order that such a current may traverse the wire of a multiplier, it must pass through the liquid, which cannot transmit the feeblest current without electrolysis. The appearance of the polarization current therefore is inseparably connected with the beginning of the electrolysis of the liquid; the current cannot exist in any case when the electrical difference in the two surfaces in contact is not sufficient to bring about electrolysis.

For example, if the water acidified by sulphuric acid on one side be terminated by a pure gold or silver plate, and on the other side by one coated with a stratum of hydrogen, no current appears on connecting the two plates, because the hydrogen of the gold plate is not in the condition to attract the oxygen of the nearest particle of water, and thus to produce electrolysis throughout the whole stratum of liquid; but if platinum be used instead of the gold plate, the peculiar relation of this metal to hydrogen and oxygen induces electrolysis by causing the hydrogen nearest the platinum plate to attract the oxygen from its neighboring particle of water, and thus the decomposition and recomposition of water extends to the other plate. Thus it is shown why the experiment No. 1 succeeds with platinum plates, but not with gold or silver.

Schönbein considers it not improbable that this action is produced by a sub-oxide of hydrogen, the hydrogen of which has a greater deoxidizing force than pure hydrogen, as the third atom of oxygen of the super-oxide shows a greater affinity for oxidable bodies than pure oxygen.

A platinum plate immersed in chlorine gas, combined voltaically with a clean one in dilute sulphuric acid, yields a current, because, in this combination, the affinity of the chlorine is sufficiently strong to attract the hydrogen from the nearest molecule of water, and form hydrochloric acid; hence the electrolysis of the water is induced all the wayto the other plate. Even if gold and silver plates be used in this experiment, the chlorine has the power of decomposing water; hence, in this case, the current which passes, of course, in the direction in which the particles of hydrogen go, continues until the chlorine on one of the plates disappears.

The formation of the current in experiment No. 3 is to be explained in a manner entirely analogous to this.

But, by using pure oxygen instead of chlorine or bromine, in the above combination, it is not found in such a state of activity, to use Schönbein's language, as to cause the decomposition of the nearest particle of water; hence the absence of the current in the experiments No. 7 (in section 39,) and No. 2 (in section 40.)

But if pure oxygen in this case cannot excite a current of polarization, how is the negative polarization of a platinum plate, which has served as a positive electrode, to be explained? Certainly not by the oxygen evolved at its surface. Ozone, as well as oxygen, escapes at the positive electrode, and that this remarkable body can polarize platinum plates negatively has been stated.

According to Schönbein, ozone is a super-oxide of hydrogen; a view which is strongly supported by the fact that the super-oxides of metals have a precisely similar voltaic action. The third atom of oxygen has a greater affinity for oxidable bodies than free oxygen, and thus the strong electro-negative action of these substances is explained.

§ 42. *Hyper-oxide batteries.*—A platinum plate, covered with a hyper-oxide, as, for instance, hyper-oxide of lead, acts electro-negatively towards a clean platinum plate. On immersing the two plates connected with the terminal wires of a multiplier, in dilute sulphuric acid, a powerful current arises, passing from the clean plate to the one covered with the hyper-oxide. The third atom of oxygen in the hyper-oxide attracts from the nearest molecule of water its hydrogen, and thus causes electrolysis throughout the whole liquid.

To cover a platinum plate with hyper-oxide of lead, it is connected with the positive pole of a battery of several pairs, whose negative pole is connected with a similar platinum plate. The two plates are now immersed in a solution of nitrate of lead, when the positive plate is at once covered with a layer of super-oxide of the metal.

The current which a polarized platinum plate yields with a clean one, is, of course, transient; it disappears with the electro-motive coating of the plate, and this is removed necessarily in consequence of the formation of the current.

For example, let us consider a positive platinum plate polarized by hydrogen; this being combined with a clean platinum plate, a current arises which passes from the coated to the clean plate; thus, at the coated plate, in consequence of the current, oxygen will escape, and combine with the hydrogen which appears there.

In like manner, the strata of chlorine, hyper-oxide of lead, &c., with which the platinum plate has been negatively polarized, gradually disappear, the chlorine or oxygen of the super-oxide combining with the hydrogen escaping at this plate.

Since platinum plates polarized by hyper-oxide are more strongly electro-negative than clean plates, by combining plates of zinc and platinum covered with hyper-oxide of lead, exceedingly powerful galvanic batteries can be constructed.

The practical application of such batteries is as yet opposed by the fact that the stratum of super-oxide, the production of which is somewhat troublesome, very soon disappears.

Wheatstone has given us a measurement of the electro-motive force of the hyper-oxide battery in the memoir already cited (Pog. Ann. LXII, 522.) He found for the electro-motive force of—

1.	Zinc amalgam, sulphate of copper, copper	30	470
2.	Zinc amalgam, dilute sulphuric acid, copper	20	313
3.	Zinc amalgam, chloride of platinum, platinum	40	626
4.	Zinc amalgam, dilute sulphuric acid, platinum	27	423
5.	Potassa amalgam, sulphate of copper, copper	59	924
6.	Potassa amalgam, chloride of platinum, platinum	69	1081
7.	Potassa amalgam, sulphate of zinc, zinc	29	451
8.	Zinc amalgam, dilute sulphuric acid, hyper-oxide of lead	68	1065
9.	Potassa amalgam, dilute sulphuric acid, hyper-oxide of lead	98	1535
10.	Zinc amalgam, dilute sulphuric acid, hyper-oxide of manganese	54	846
11.	Potassa amalgam, dilute sulphuric acid, hyper-oxide of manganese	84	1316

The first column of figures contains the values of the electro-motive forces measured by revolutions of Wheatstone's rheostat; the last column gives the values reduced to chemical measure, assuming that the electro-motive force of the first combination is equal to that of Daniell's battery.

We see here how much greater an electro-motive force the combination of amalgamated zinc with hyper-oxide of lead indicates, than amalgamated zinc and platinum, even if care is taken, as in No. 3, to prevent galvanic polarization from taking place at the negative metal.

The combination No. 3 is one of zinc and platinum corresponding to Daniell's battery. Metallic platinum will be separated from the solution of chloride and deposited upon the platinum' plate by the current, thus hindering galvanic polarization, as in Daniell's battery by the deposition of copper. We can thus consider the numerical value of No. 3 above, namely, 626, as the measure of the electrical difference between amalgamated zinc and platinum.

Comparing the electro-motive force of No. 3 with that of Grove's battery, we find a considerable difference, since the former is only 626, the latter 777, or according to my measurements 829, (section 18.)

I think I can conclude from this difference that the nitric acid in Grove's, as well as Bunsen's battery, not only prevents polarization by the removal of oxygen, *but that it acts as an electro-motor, also in the manner of the hyper-oxide.* A circumstance which renders this view still more probable is this—that the electro-motive force of a combination of hyper-oxide of manganese with zinc, (No. 10,) is not sensibly greater than that of Grove and Bunsen's battery.

The above table also shows how considerably the electro-motive force can be augmented by replacing the electro-positive amalgam of zinc, by the still more electro-positive amalgam of potassium; the expense of the latter amalgam, however, renders its practical application in such batteries impossible.

§ 43. *Grove's gas battery.*—Grove's battery can be understood from Fig. 29, which represents a single element.

Fig. 29.

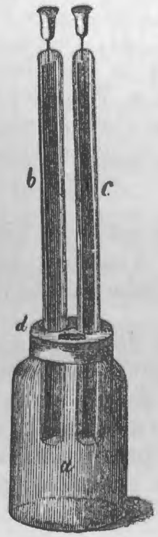
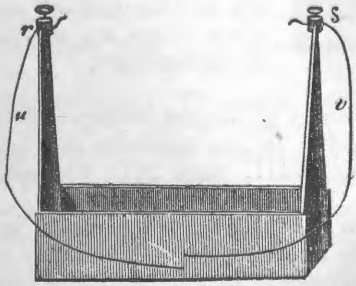


Fig. 30.



A varnished metallic cover is fastened air-tight on the glass jar *a*. This cover has three openings; the glass tubes *b* and *c* pass air-tight through two of them. The third is somewhat larger and can be closed by a stopper. Each of the tubes is 30 centimetres long and 1.8 centimetre in diameter. At the upper end of each tube a platinum wire is fused into the glass, having at the top a cup for mercury, and to the other end of the wire a platinized platinum plate is soldered, which extends nearly to the lower end of the tube.

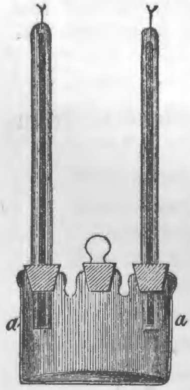
The following is the process for charging such an element: Fill the vessel *a* with water, through the opening *d;* close *d* and then invert the whole apparatus; in this way the tubes *b* and *c* are filled with water. After restoring the element to an upright position, pass through the opening *d* the connecting tube of the gas apparatus. One of the tubes is filled in this way with hydrogen, and the other with oxygen to about $\frac{3}{4}$ the entire length.

Fig. 30 represents a wooden trough intended to hold four such elements; it is exhibited on a scale one-fourth of that of Fig. 29. The elements being in position, the small mercury cups are connected by copper wires; into the last cup to the left a wire passes from the binding screw *r*, and into the last cup to the right, one from the binding screw *s*. The poles *u* and *v* are fixed in the two binding screws.

This form of the gas battery is almost exactly the same as that which Grove describes as the most convenient, in the appendix to a memoir: "*On the voltaic gas battery, its application to eudiometry.*" (Phil. Trans. 1843, Pt II, page 51; Pogg. Ann. im Ergänzungband II, 1848.) The arrangement, however, described in the memoir, admits of the removal of the tubes for the purpose of examining the gases.

For this purpose the tubes *b* and *c* must not be cemented into the cover of the vessel *a*, but they must be inserted through corks so that they can be removed and replaced at pleasure. Fig. 31, represents the arrangement indicated by Grove in the above cited paper; *a a* is a glass vessel like a Woulfe's bottle; the middle opening is closed by a glass stopper; the glass tubes are adapted to the other openings by ground collars.

Fig. 31.



§ 44. *Theory of the gas battery.*—Schönbein has set forth his views on this subject in two memoirs in Poggendorff's Annalen; the first in volume LVIII, page 361; the second in volume LXXIV, page 241.

His view is, "that the hydrogen, in the above described arrangement, with reference to the generation of the current, plays a primary, and the oxygen only a secondary or depolarizing part."

The hydrogen alone is certainly able to generate a current of polarization, as Schönbein's experiments (in section 39) prove. A platinum plate, immersed but a short time in an atmosphere of hydrogen, gives, in combination with a clean platinum plate, a current, even if the liquid in which they are immersed contain no free oxygen. Therefore, it is clear that a Grove's battery must yield a current if one half the tube is entirely filled with acidified water, while the other half contains hydrogen, even if all free oxygen has been previously expelled from the liquid, and the entrance of atmospheric air is prevented.

This current will soon cease, because, in consequence of it, the hydrogen disappears from the platinum plate not previously in contact with gas, and, therefore, the difference which caused the formation of the current disappears.

If the current is to continue, then the hydrogen escaping at the other side, in consequence of the current, must be removed, and this is, according to Schönbein's view, the function of the oxygen in the gas battery.

Schönbein, therefore, holds the opinion, that oxygen does not act in the gas battery as an electro-motor, but only as a depolarizer. He sustains this opinion by the observation, the credibility of which is unjustly disputed by the editor of the "Jahresbericht von Liebig und Kopp," that *pure* oxygen is unable to polarize a plate in the same manner as hydrogen does.

The numerical values before given for the polarization of platinum plates in different gases, renders it possible to state the question in precise terms.

The entire polarization in a voltameter is at a maximum about 1200; one-half of this polarization is due to the plate coated with hydrogen, the other half to the positive platinum plate coated with oxygen containing *ozone*. Now the question is: Is the electro-motive force of an element of the Grove gas battery equal to 1200; or is it, according to Schönbein's view, only 600?

Although a platinum plate coated with pure oxygen, combined with another in acidified water, generates no current, yet there is here always an electrical difference, even though it should not be sufficient to bring about decomposition in the intermediate stratum of water; hence it is probable, that the electro-motive force of a Grove gas element, charged with hydrogen and pure oxygen, is greater than 600, if it does not attain the value 1200.

At the first glance, nothing appears easier than to decide this question by measuring directly the electro-motive force of the gas battery; but a closer examination shows that such a measurement is utterly impossible. The platinum plates of the gas pile are not entirely coated with gas, but only partially. Therefore, we have here a similar case to that in which one of a pair of platinum plates is partially covered with zinc. By applying the different methods for determining the electro-motive force of the current, which here traverses the wire connecting the platinum plates, we shall certainly not obtain the true value of the electrical difference between zinc and platinum, (wholly disregarding the polarization which appears at the clean platinum plate). On account of the partial coating of the platinum plate with gas, lateral currents are formed, so that the current, which traverses the closing wire, is only a part of the effect produced by the electrical opposition in the battery; hence, also, in part, the exceedingly feeble force of the current in the gas pile.

§ 45. *Effects of the gas pile.*—Grove obtained the following effects with a gas battery of 50 elements:

1. A shock which could be felt by five persons joining hands.
2. In a moderately sensitive galvanometer, the current produced a constant deflection of 60°.
3. Considerable divergence of a gold leaf electroscope.
4. Between charcoal points a spark visible in full day-light.
5. Electrolytic decomposition of iodide of potassium and acidified water.

To produce a sensible decomposition of water, from cells of the above described construction, four elements are sufficient. A single cell decomposes iodide of potassium.

A circuit of ten elements of this kind with dilute sulphuric acid of the spec. grav. 1.2, and filled alternately with hydrogen and oxygen, was closed with an interposed voltameter and left standing 36 hours. At the end of this time 2.1 cubic inches of detonating gas had been developed; in each of the hydrogen tubes 1.5 cubic inches had disappeared; in each of the oxygen tubes 0.7 cubic inch; thus, together, 2.2 cubic inches of gas had disappeared. The difference (2.2 to 2.1) is due to a small absorption of the oxygen by the water.

If a sensible current is to be produced, the platinised platinum plates must not be wholly immersed beneath the surface of the water, but they must extend partly out of the liquid into the atmosphere of gas.

A battery, whose tubes were charged alternately with hydrogen and dilute nitric acid, gave a current, and three pairs were sufficient to decompose water in an interposed voltameter.

The gas pile yields a very powerful current if chlorine is substituted for oxygen. A chlorine and hydrogen battery of two elements is sufficient to decompose water between platinum plates.

Carbonic oxide gas acts in the gas pile like hydrogen.

Other gases—for example, nitrogen—are absolutely without effect. For instance, place a mixture of nitrogen and oxygen in one tube, and hydrogen in the other; after closing the circuit all the oxygen is gradually but completely absorbed, while the nitrogen remains the same. Grove's proposition to apply the gas pile in eudiometrical experiments is based upon this.

In a second memoir, which may be found in Poggendorff's Annalen, (2to Ergänzungsbande, seite 407,) Grove describes the following remarkable experiment.

One of the tubes of the gas pile was charged with oxygen; in the other a weighed piece of phosphorus was placed by means of a small glass cup fastened to a glass rod, as represented in Fig. 32, and then the tube was partially filled with nitrogen. The apparatus indicated a current by an interposed galvanometer. After being closed four months, during which time the galvanometer constantly indicated a current, the water had increased in the oxygen tube one cubic inch, but not at all in the nitrogen tube; the piece of phosphorus, on the other hand, had become 0.4 grain lighter.

Fig. 32.

This result is easily explained; the vapor of phosphorus was diffused in the atmosphere of nitrogen, and this acted exactly like hydrogen in the ordinary gas battery.

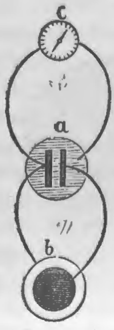
Sulphur instead of phosphorus gave no action until it was fused by means of a hot metal ring; the galvanometer was then instantly deflected.

In another experiment both tubes of the battery were charged with nitrogen, but one was provided with phosphorus, the other with iodine. After closing, a decided current appeared which lasted for months.

The nitrogen did not change in volume, but the liquid became gradually colored. Here the vapor of iodine acted like oxygen; the vapor of phosphorus like hydrogen.

§ 46. *The pole changer.*—It is well known that if two homogeneous plates, say of platinum, be immersed in dilute acid, the poles being connected even with only a single voltaic element, the galvanic polarization which they undergo if connected after the interruption of the primary current, is sufficiently strong to cause a current in the opposite direction. For example, let a, in Fig. 33, be a voltameter, b a galvanic element, sending its current through the latter; the current being interrupted, connect the terminal wires of a multiplier c with the two plates, and this will indicate a current of polarization which, however, will soon cease.

Fig. 33.

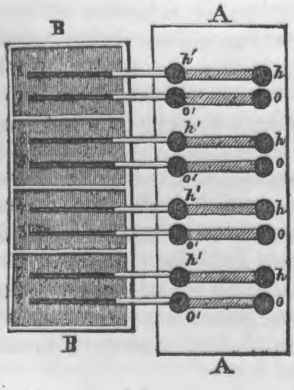


In this manner a whole series of plates can be polarized, and thus we obtain *Ritter's secondary pile*, for charging which a primitive battery of many pairs of plates is always used. The electro-motive force, which sets in motion the current of the secondary battery, is evidently less than that of the primary charging battery.

Poggendorff has invented a contrivance for charging, with a simple voltaic battery a secondary battery of any number of plates, and thus obtains a current of far greater electro-motive force than that of the charging battery itself. (Pog. Ann. LX, 568.)

The process is as follows: Suppose we have a series of pairs of platinum plates, in cells, filled with dilute sulphuric acid, as shown in Fig. 34. Plates 1 and 2 are in the first cell, 3 and 4 in the second, &c. Now, if plates 1, 3. 5, and 7 be connected with the positive pole of the simple battery, and the plates 2, 4, 6, and 8 with the negative pole, the plates denoted by the odd numbers will be negatively polarized, (since oxygen escapes at their surfaces,) and the plates denoted by even numbers will be positively polarized, (by hydrogen.)

Fig. 34.

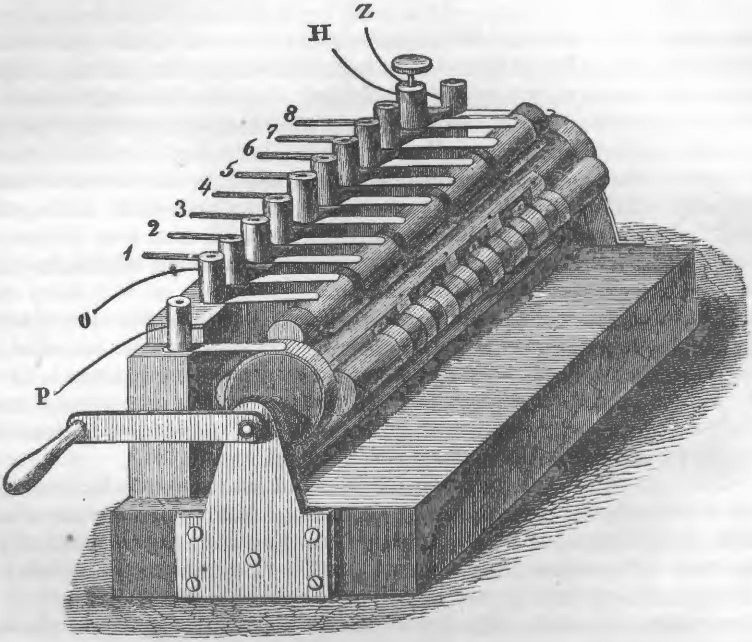


After this connexion has existed only a very short time, it must be suddenly broken, the charged plates connected according to the principle of the battery, and the circuit closed by a voltameter; this will now be traversed by a current of much greater tension than the primitive one, because in this combination the electro-motive force of all the polarized pairs of plates is added together.

For this purpose, the plates 1 and 8 must be placed in conducting connexion with the voltameter, while 2 and 3, 4 and 5, 6 and 7, must be joined by metallic wires.

Poggendorff has invented an apparatus, called the pole-changer, for effecting these changes and discharges in rapid succession. But his instrument requires the use of mercury, and I propose for the purpose the apparatus represented in Fig. 35.

Fig. 35.



On a vertical board to the left of the figure is a series of brass pillars, which serve for fastening metal wires. The screw which is used for this purpose is represented only in the one at H; all the other posts are also provided with screws. These pillars all stand on metallic springs, rubbing against a movable cylinder; the first and last pillars stand a little below the level of the others.

At each end of the cylinder a copper ring is placed. The spring of the first post (the wire from which passes towards P) rubs on the first copper ring, and the spring of the last post (whose wire goes to Z) rubs on the further ring.

These wires pass to the platinum and the zinc plates of the charging element. The wires O and H, leading to the platinum plates of the voltameter, are screwed to the first and last of the more elevated pillars.

The wires 1, 2, 3, 4, 5, 6, 7, 8, which are screwed in the other posts, pass to the platinum plates of the secondary battery.

On the movable wooden cylinder are placed four semicircular wooden bars, 90° apart, which are partly covered with bands of copper; the springs of the high posts rub upon these alternately during the revolution.

On the bar which is represented as uppermost in the cut, and on which the springs are resting, the copper bands are so arranged that 1 is brought into conducting connexion with O, 2 with 3, 4 with 5, 6 with 7, and 8 with H; in like manner the platinum plates from 1 to 8 are combined according to the principle of the battery, and closed by the voltameter.

The lower wooden bar has exactly the same construction as the upper one.

The other two bars opposite each other, to the right and left of the cylinder, are also alike, and so constructed that when they come into contact with the springs, the plates 2, 4, 6, and 8 are in conducting connexion with the carbon cylinder, and 1, 3, 5, and 7 with the zinc cylinder of the charging element.

For ready expression, we shall call the rollers which are above and below in the cut the discharging rollers; the others the charging rollers.

The construction of the charging rollers is as follows: Eight copper bands are placed on the wooden roller in such a way that they may come in contact with the eight springs corresponding to the eight platinum plates. Half of these bands (the 2d, 4th, 6th, and 8th from the first in one figure) are connected with a copper strip, which passes to the front ring of the cylinder, and thus to P. In the same manner the other half of the copper bands (1, 3, 5, and 7) are connected with a similar strip of copper, which, lying on the other side of the wooden bar, is not visible in the figure, and which passes to the farther copper ring of the cylinder, thence to Z; thus the bands 1, 3, 5, and 7 are in connexion with the zinc cylinder, and 2, 4, 6, and 8 with the carbon cylinder of the charging element, when the charging roller is uppermost.

The cylinder is turned by the crank; at each revolution there is a double charge and discharge of the secondary pile. The most suitable dimensions for the cylinder are 12 centimetres long, (for a pile of 4 pair of plates,) and (without the bars) 2½ to 3 centimetres in diameter.

It is well known that with one Grove's element very little water can be decomposed; the voltameter plates become coated with gas bubbles, but very few ascend. But on using the simple battery through the medium of the pole-changer for charging the secondary battery, in whose circuit the voltameter is inserted, a lively decomposition of water is obtained as soon as the pole-changer is set in motion, which is a striking proof that the electro-motive force of the secondary current is considerably stronger than that of the primary.

With a voltameter whose plates presented a surface on each side of about 3 square inches, sulphuric acid being added to the water, Poggendorff obtained from 5 to 6 cubic centimetres of explosive gas per minute, when in this time the circuit was closed and opened about 80 times.

The secondary current thus obtained has an electro-motive force which exceeds that of the primary current in proportion as the pairs of plates of the secondary battery are more numerous. On the other hand, the entire chemical effect which the secondary current produces in the voltameter is only $\frac{1}{n}$ (if the secondary battery consists of n pair of plates) of that which the primary current had previously produced in each separate cell for charging the plates. For, while 6 cubic centimetres of explosive gas were collected in the voltameter in the above-mentioned experiment, 6 cubic centimetres of this gas had to unite to form water *in each* of the four cells of the charging battery, and this quantity of gas was first released from the water by the action of the primary battery. Therefore by the action of this battery in the 4 cells together, the water of $6 \times 4 = 24$ cubic centimetres of gas must be electrolyzed per minute, in order that 6 cubic centimetres may be released in the voltameter.

Without the pole-changer and by the direct action of the simple battery in the four cells, (which in this combination represent a large pair of plates,) not over 0.1 cubic centimetre of gas would be evolved, because the gas, which appears at the first moment of the passage of the current, produces at once a polarization of the plates, in consequence of which only an exceedingly feeble current can circulate; but by the pole-changer this polarization is immediately removed, and thus an undiminished action of the charging cells is rendered possible.

The platinum plates, of which Poggendorff constructed his secondary battery, were *platinized.* If the secondary current is to be tolerably strong, this is very necessary; at least the negative plates of the secondary battery must be platinized, *i. e.* those at which the primary current has evolved oxygen, and to which the secondary current carries hydrogen. The influence of platinizing appears from the following experiments made by Poggendorff:

In five minutes a battery of two pairs of platinum plates connected with a small Grove's element and the pole-changer yielded the following quantities of gas:

1. All the plates uncoated..............	1 c. c. (a little over.)
2. The positive plates platinized.......	1.5 "
3. The negative " "	13 to 14 c. c.
4. All the plates platinized............	13 to 14 "

The positive plates are those at which the original current evolves hydrogen.

This is not due to the platinized plates being more strongly polarized, for in fact they are less so than the naked ones; but, in Poggendorff's opinion, the action of the platinum coating consists in favoring the combination of the oxygen, separated at its surface by the primary current, with the nascent hydrogen evolved in consequence of the secondary. Much might be said in opposition to the *modus operandi* as explained by Poggendorff; but this is not exactly the place for the discussion.

Poggendorff has successfully used plates of Bunsen's carbon in constructing secondary batteries. A battery of two pairs of such plates

1 inch wide and 1.5 deep, immersed in dilute acid, yielded 8 cubic centimetres in five minutes.

The current of polarization which such a secondary battery yields by means of the pole-changer is considerably stronger than that of a Grove's gas-battery. The intermitting current of a secondary battery of two pairs of plates gave in one minute with the pole-changer $\frac{14}{5} =$ 2.8 c. c. of gas, while the continuous current of a gas-battery of ten cells yield only 2.1 cubic inches in thirty-six hours; thus only about 0.016 cubic centimetre of gas per minute.

§ 47. *Old observations on the relation of iron to nitric acid.*—On immersing an iron wire in nitric acid of the specific gravity 1.4, it instantly turns brown, while red vapor escapes with more or less effervescence. This, however, soon ceases; the iron recovers its metallic lustre, and retains it as long as it remains in the acid without being further attacked. Once placed in this state of chemical inactivity, such a wire will remain so even in dilute acid, which of itself could not have produced this condition.

This remarkable relation of iron to nitric acid was observed as early as the last century by James Keir, and published in the Phil. Trans. for 1790; but the phenomenon was too much isolated to allow a true determination of its nature, and thus Keir's observation was forgotten.

After the lapse of thirty-seven years, Wetzlar made similar observations, which he published in Schweigger's Jahrbuch der Chemie und Physik; Bd. 49, S. 470; Bd. 50, S. 88 and 129; Bd. 56, S. 206. In England, Herschell took up this subject, (Pogg. Ann., XXXII, 211; Ann. de Chemie et de Phys., 1833, vol. LIV, 87,) and Fechner observed similar phenomena in the action of nitrate of silver on iron. Schönbein has prosecuted this subject most zealously, and to him belongs the merit of having extended, more than any one else, the circle of the phenomena relating to it.

Since Schönbein has investigated the phenomena of the *passivity of iron* (a term which was introduced by himself) the most thoroughly, it may be advisable to take our facts chiefly from his memoirs. This distinguished natural philosopher, however, will, I hope, not take offence if I should venture the remark, that the peculiar diffuseness which characterizes these papers renders them difficult to understand.

§ 48. *Schönbein's observations on the passivity of iron.*—His first paper on this subject may be found in Poggendorff's Annalen, XXXVII, 390.

"It has long been known," Schönbein begins, "that very concentrated nitric acid does not attack many metals, which are oxidized with violence by the same acid containing more water. Of these metals *tin* is one, but iron more especially has this characteristic.

"An iron shaving perfectly free from rust was not attacked by nitric acid of the specific gravity of 1.5. Even after adding to the acid as much water as will dilute it to the degree at which it would attack fresh iron shavings violently, the shaving thus treated will remain perfectly *passive.*

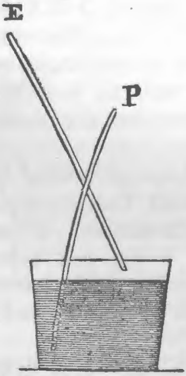
"It is not only the treatment with concentrated nitric acid which produces this passivity. Iron filings, heated for only a few seconds over a spirit-lamp, are not attacked either by concentrated or dilute nitric acid."

These experiments may be made much more conveniently with iron wires. An iron wire placed in nitric acid of the specific gravity of 1.5, becomes passive; and it assumes the same condition if heated in a spirit-flame to iridescence. The wire thus rendered passive can then be dipped in dilute acid without being attacked, while an ordinary iron wire would occasion a violent liberation of gas. The dilution of the acid cannot exceed a certain limit, which as yet is not ascertained. Schönbein has determined that nitric acid of 1.36 specific gravity, diluted with 15 and more volumes of water, attacked heated iron wire as it does ordinary wire.

By exposing an iron wire to nitric acid of the spec. grav. 1.35, it will be attacked with great violence. On removing the wire from the acid after a second, and holding it a few moments in the air, and then returning it to the liquid, the action of the acid on the iron will be perceptibly weaker. After three or four alternate immersions and removals, a tolerably slow action appears; and, at the fifth, or, at the latest, at the sixth immersion, absolute chemical indifference takes place, exhibited in the perfect metallic lustre of the surface of the wire thus treated, which generally characterizes the iron rendered passive in nitric acid.

From these facts, there does not appear to be the least relation between the passivity of iron and its electrical properties; but that such relations do exist may be shown by the following method of inducing the condition.

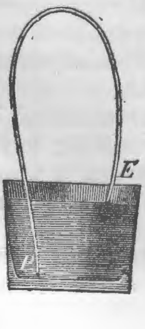
Fig. 36.



First dip in nitric acid, of the spec. grav. 1.35, a platinum wire P, Fig. 36; touch it with a well-cleaned iron wire, and the latter wire will not be attacked by the acid when immersed, so long as it remains in contact with the platinum wire, although the same wire alone would be at once attacked by the acid.

If, instead of the platinum wire, the iridized end of an iron wire, thus rendered passive, be immersed in the liquid, it will play the part of the platinum wire, in the above experiment, perfectly. Fig. 37 represents a variation of this experiment. The iridized and hence passive end of an iron wire is immersed in nitric acid of the spec. grav. 1.35, and is not attacked. Now bend it so that the end E, which was not heated, dips into the acid. No action takes place; but if the end E be placed in the acid without P, violent action will occur.

Fig. 37.



It should be added that these phenomena no longer appear when the temperature of the acid is raised to 80°, and that they are the weaker, the nearer the acid is to this degree of temperature.

If the wire E, Fig. 36, be thrust into the liquid while it is in contact with P, the latter may be altogether removed without E losing its passivity; indeed, with the wire E thus rendered passive, the same state can be communicated to an ordinary iron wire in the same manner as it is given by P to E.

The experiment, of which the plan is sketched in Fig. 38, is of special importance in reference to the theory of passivity. At one of the ends of a galvanometer an iridized iron wire is fastened, and at the other an ordinary iron wire. Now, first dipping the passive and then the other wire into nitric acid of 1.35 spec. grav., the galvanometer indicates a transient current, passing in the direction from the unchanged iron, through the liquid, to the iridized iron.

Fig. 38.

These experiments afford us a deep insight into the nature of the passivity of iron. In the first place, it is evident that by heating the wire the coating of oxide thus formed protects it from the action of the acid, and thus the idea is very obvious, that passive iron, even in cases where such a coating is not visible, as, for instance, an immersion in concentrated nitric acid, owes this property to a thin film of oxide. But then the circumstance, that the platinum wire, in Fig. 36, can be exchanged for the heated iron wire, shows that the oxide of iron formed by heating to redness performs the functions of platinum, that by such a coating the iron, in a certain measure, suffers negative galvanic polarization.

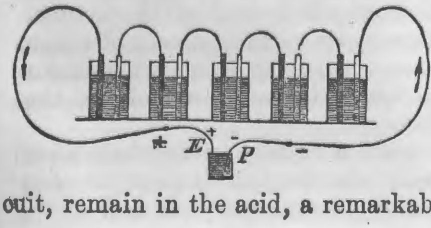
All passive iron wires are changed into active in hot acid; yet, in the facility with which they change their state, there appears a considerable difference between those which are made passive by a red heat and such as are rendered passive by contact with a wire already passive, on being immersed in the liquid. We will term the former *primary passive*, the latter *secondary passive*. The first owes the longer continuance of its passivity to a thicker coating of oxide.

Everything which destroys the protecting coat, renders the wire active again.

§ 49. *Action of iron electrodes.*—In the experiment represented by Fig. 36, E evidently forms the positive pole of a *simple* circuit; therefore it might be supposed that iron would be made passive by dipping it, as the positive pole of a voltaic pile, in an acid, which would attack it.

Schönbein has actually made this experiment, (Pog. Ann. XXXVII, 391.) To the positive pole of a circuit consisting of 15 inconstant zinc and copper elements, an iron wire was fastened, while the negative pole terminated in a platinum wire. The negative platinum wire was first dipped in a vessel of nitric acid of 1.36 sp. gr., and the circuit was then closed by the immersion of the positive pole, formed of the iron wire, in the same acid, as shown in Fig. 39. The iron wire appeared perfectly passive, and after separation from the battery, possessed the same properties as a wire made passive by being heated red-hot.

Fig. 39.



If the passive iron wire, continuing as the + pole of the circuit, remain in the acid, a remarkable phenomenon is exhibited. The oxygen liberated at this pole, in consequence of the electrolysis, does not combine with the iron, but ascends free from it, exactly as though the + pole of the circuit were formed of a platinum wire. Therefore the stratum of oxide which is formed under the above-mentioned circumstances, immediately on the immersion of the iron wire in the liquid, protects it completely from further oxidation.

Nitric acid of 1.35 sp. gr. is not essential to the success of this experiment; it may be diluted with 100 volumes of water, and yet the iron positive pole immersed in the liquid will become passive, and the oxygen liberated at it will ascend as free gas.

Precisely similar phenomena take place if dilute sulphuric or phosphoric acid be used instead of dilute nitric acid. To obtain free oxygen at the positive iron wire, the negative pole must be first dipped in the liquid, and then the iron wire connected with the positive pole is placed in it.

If the positive wire be dipped in the acid before the negative, it will be attacked; the iron wire will not become passive, if, separated from the positive pole of the battery, it be dipped in the dilute acid, no matter whether the negative pole be already in it or not. In short, if iron is to be made passive, the chemical action of the dilute acid must not precede the action of the current.

If, instead of the dilute acid in this experiment, the liquid solution of an oxygen compound be used, which exerts no sensible chemical action on iron, as solutions of alkalis and perfectly neutral salts, the iron will become passive, as though the battery were closed. In using potash lye, or a solution of nitrate of soda, the iron connected with the positive pole will become passive, no matter whether the negative or positive pole be first placed in the liquid. (Pogg. Ann. XXXVIII, 492.)

Upon this is based the construction of voltameters, which are formed of iron plates immersed in a solution of potash.

Fig. 40.

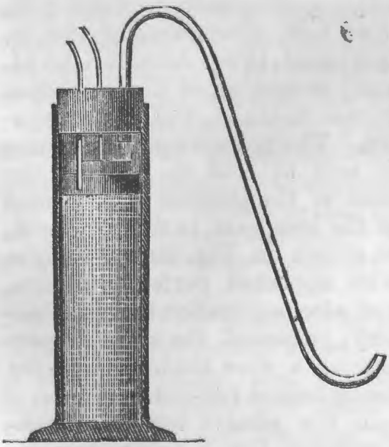


Fig. 40 represents a voltameter constructed of iron plates by Bunsen. In a cylindrical glass receiver 6 to 8 centimetres in diameter, and 30 to 35 centimetres in height, there are two concentric cylinders of sheet-iron, which are kept apart by a substance at once insulating and not liable to be attacked by a solution of potash, such as strands of spun glass. The vessel filled with this solution is closed by a suitable cork through which, besides the gas tube, two copper wires pass, each of which is soldered to an iron plate, and put in connexion with the poles of the battery.

Such a battery having been once well constructed, it can be left standing, filled with the potash solution, always ready for use.

To prevent a strong disturbance of the solution during the development of gas, a film of turpentine oil, about one line thick, is poured upon the surface.

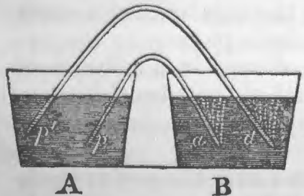
A voltameter, with moderately large electrodes, can be made by means of iron plates, in the same manner, at little cost. Such a voltameter is capable of yielding a large quantity of gas in a short time; yet the development is not near so great as might be expected from the magnitude of the plates, probably because the potash solution is a worse conductor than the dilute sulphuric acid of the ordinary platinum voltameter.

Such an iron plate voltameter, according to my observations, is not well adapted to exact experiments. I have noticed that the maximum development of gas takes place some time after the closing of the battery, and that the appearance of the gas bubbles does not cease with the interruption of the current, but lasts considerably longer. This is due to the absorption of the gas by the liquid.

While with the use of alkaline solution in water and perfectly neutral salts, iron is passive, however the circuit may be closed, on the other hand iron never becomes passive, however the closing may be effected, if the iron electrodes be immersed in a solution of an electrolytic compound not containing oxygen, whose negative component has a great affinity for iron, such as the hydracids, halogen salts, sulphurets, &c. In such solutions iron is always attacked, and free oxygen is never liberated at its surface.

In the experiments described in section 48, the primary passive and secondary passive ends of the wire were dipped in the same vessel filled with acid. Schönbein has extended the phenomena by using two vessels filled with acid, connected in different ways.

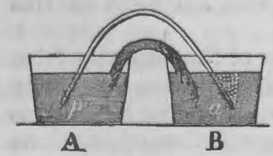
Fig. 41.



The vessels A and B, Fig. 41, are filled with nitric acid from 1.3 to 1.36 sp. gr. Dip the end of the wire *p*, rendered passive by red heat, in A, and the unheated end *a* in B; then *a* will be attacked. If a second fork of iron wire, both ends of which have not been heated, be now immersed, *d* being first put in B, and then *p'* in A, *p* will become passive, *p* and *p'* will remain free from attack, while at *a* and *d* a lively development of gas will occur.

This is not essentially different from the form of the experiment represented in Fig. 37.

Fig. 42.



Let the vessels A and B, Fig. 42, filled with acid of the sp. grav. 1.3 to 1.37, be connected by an asbestos cord saturated with the same acid. Immerse in A the passive end of an iron wire, and then the other end *a* in B; *a* will not become passive, but will be briskly attacked.

Here, evidently, the current is on account of the great resistance, too weak to render *a* passive. The correctness of this view is proved by the fact, that if the negative pole of a battery, formed of platinum or passive iron wire, be dipped in A, and then, after this, an iron wire be connected with the negative pole, the iron wire will become passive.

The cord of asbestos, in the experiment, Fig. 42, being replaced by a siphon filled with acid, the consequence will be the same; that is, the wire immersed last will not become passive.

The same result is obtained by connecting the vessels by a platinum wire instead of a siphon. Here the galvanic polarization of the platinum is the cause of the decrease of the current.

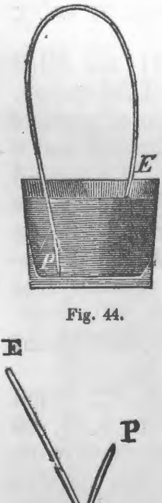
If the platinum wire be replaced by one of a metal which is attacked by the acid, the cause of the weakening of the current by the platinum disappears, and in this case the end *a* of the iron wire last dipped in B becomes passive.

§ 50. *Passive iron in a solution of sulphate of copper.*—An iron wire connected with the positive pole of a pile, and introduced into a solution of sulphate of copper which is already connected with the negative pole, Fig. 43, acts indifferently towards this liquid; that is, no copper precipitates on this wire, and there is no oxygen developed at its surface.

This passivity of iron does not appear when the circnit is closed in any other way than that mentioned.

An iron wire, which has been rendered passive by a single immersion in very concentrated nitric acid, or by repeated immersions in ordinary acid, also shows this passivity towards a solution of sulphate of copper; that is, it no longer possesses the power of attracting oxygen from the liquid, and thus of precipitating its copper.

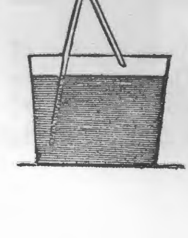
Fig. 43.



By repeating the experiment represented in Fig. 43, after having exchanged the nitric acid for a solution of sulphate of copper, it appears that the passivity cannot be transferred from the passive end of the wire P to the other end E, as was the case with the nitric acid; that is, if the end P, made passive by immersion in concentrated acid, be dipped in a solution of sulphate of copper, and the end of the wire E be then placed also in the liquid, copper will be precipitated at E.

Since an iron wire, connected with the positive pole of a pile, acts in an entirely different manner, Schönbein justly imagined that the experiment represented by Fig. 43, made with a solution of sulphate of copper, yielded a negative result only, because the current, which should have rendered the end of the wire last immersed passive, was too weak in this simple battery.

Fig. 44.

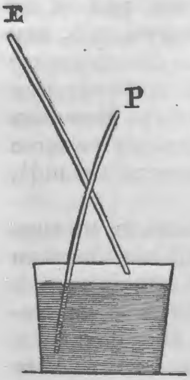


For this reason, the transfer of the passivity from one iron wire to the other, which we have previously mentioned, and which is represented in Fig. 44, is generally not possible when a solution of sulphate of copper is used instead of nitric acid.

If the current can be strengthened by making the wire P more negative than a platinum or passive iron wire, the transfer must also be possible in a solution of sulphate of copper. Starting from this consideration, Schönbein decided upon the following form for the experiment. One of the ends of a long iron wire was coated with hyper-oxide of lead, and the end P thus prepared was immersed in a solution of sulphate of copper; the wire was then bent, and the unprepared end E was also immersed in the liquid. E indicated passivity; no copper was precipitated.

While E was becoming passive, the hyper-oxide of lead gradually disappeared at P, and P became active as soon as the hyper-oxide which covered this end had totally disappeared.

Fig. 45.



In the transfer of passivity from one iron wire to another in nitric acid, represented in Fig. 45, the protecting film of oxide on E is evidently produced by the necessary quantity of oxygen being immediately brought by the current to the end E of the wire. But the current, which liberates oxygen at E, must develop hydrogen at P, which attracts the oxygen from the protecting oxide film of P; thus one would think that the same current which occasions the formation of the protecting film around E, must also occasion its removal from P; or, in other words, that rendering E passive would make P active, provided that P itself is only a secondary passive wire, and consequently not protected by a very thick film.

But the experiment shows, that with a secondary passive wire, in nitric acid of 1.36 specific gravity, another can be made passive without the first becoming active, which is probably owing to the fact that the hydrogen set free is, at least in part, oxidized by the nitric acid, and thus the film of oxide cannot be wholly reduced. But if the current should continue longer, as is the case when instead of E a zinc or copper strip be let down into the acid at P, neither of which becomes passive, the protecting film will be immediately dissolved from P, and P itself will become active.

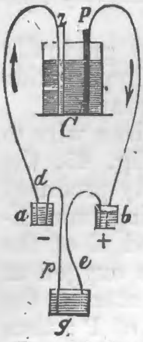
P can be rendered active again, even with an iron wire, if dilute acid be used.

§51. *Pulsations of passivity.*—With reference to the energy with which the nitric acid attacks an iron wire, there are two principal degrees to be distinguished, which we shall call the *slow* and the *rapid action.* The slow action is characterized by ceasing, instantly, as soon as the iron wire is touched by a platinum wire immersed in the acid; the iron thus exposed to the slow action of the acid became passive in this way. On an iron wire which is exposed to the rapid action of the acid, and on which a lively development of gas takes place, this treatment with a platinum wire has no influence; it does not become passive by such means.

If an iron wire, rendered passive by repeated immersions in nitric acid of the spec. grav. 1.35, be touched, while yet in the liquid, with a copper or brass wire, which is at the same time dipped into the acid, the iron wire, as already shown, becomes active, and is subjected to *slow action.* This activity, however, is not constant, but intermittent;

or, in other words, under such circumstances it becomes alternately active and passive, and this happens at first at intervals of about one second, but during the course of the action the intervals become shorter until finally rapid action commences.

Fig. 46.



Let each of the conducting wires of a powerful simple battery C, Fig. 46, pass into a small cup filled with mercury, and connect the cup *a* in which the negative wire dips by a platinum strip *p*, with the liquid (11 parts by vol. of water to 1 part of sulphuric acid) of the decomposing cell *g;* then dip one end of an ordinary iron wire *e* in the positive mercury cup *b*, and the other end in the acidified water in the decomposing cell; the iron will become passive, and no hydrogen will be developed at the platinum electrode *p*, since, on account of the polarization at *p*, the electro-motive force of C will not suffice to send a sensible current through *g*.

But if the battery be closed in another way, for instance, so that the iron wire *e* may first dip in *g* and then in *b*, it will not become passive; *g* itself becomes an exciting cell, whose current combines with that of the constant elements, and thus a lively development of hydrogen will appear at *p*, during which the iron wire is dissolved.

If the battery be so closed that *e* is passive, and that consequently no hydrogen rises at *p*, various expedients may be adopted to make *e* again active, so that the gas may begin to appear at *p*. One of the means of producing this development consists in interrupting the circuit at any point, and after a short time closing it again; for example, by drawing out the wire *d* from *a*, *e* at once becomes active, and if *d* be now immersed again, a lively development takes place at the platinum strip *p*.

To obtain the passivity of *e*, the constant element must tend to drive the current though *g* with a certain energy, on which account it will cease when the circuit is interrupted. The energy with which the constant element tends to drive the current through *g*, can be weakened by introducing a good lateral circuit.

If the mercury cups *a* and *b* be connected by a short thick copper wire, nearly the whole current which the constant element is able to generate, will pass through it; *e* loses its passivity, and part of the current generated by C passes through *g*, and exhibits itself by a development of gas.

On the contrary, if while *e* is yet passive, *a* and *b* be connected by a wire, which exerts considerable resistance, the current which it can conduct is too feeble to overcome the passivity of the iron wire *e;* by such a wire no development of gas at *p* can be produced.

Between these two limits of conductive capacity of the wires connecting the mercury cups *a* and *b*—namely, the very good conducting wire, through which the passivity of *e* is totally destroyed, and a continuous development of gas at *p* is produced, and the very bad conducting wire which cannot destroy the passivity of *e*—there is a certain intermediate length of wire, by means of which the passivity of *e* is alternately destroyed and reproduced, so that at *p* a pulsating development of gas takes place.

The length and thickness of the wires which produce the effect described, depend upon circumstances. Schönbein in his experiments obtained with a copper wire 3 inches long, and ½ an inch thick, a constant liberation of gas at *p*. A wire 40 feet long of the same thickness did not destroy the passivity of *e*. A wire of the same thickness and 16 to 20 feet long produced the pulsations mentioned above. After closing, a short time elapsed before the gas began to appear at *p*; it was more lively than that which was produced by shorter wires, but ceased again after a few seconds, and soon began again. This alternate action and inaction continued, until at last a constant state of inaction occurred. (Pog. Ann. LVII, 63.)

§52. *Theory of passivity.*—Upon a review of the foregoing facts, the theory of passivity can hardly be doubtful; it will appear readily from the general phenomena, though there are many single facts which need closer investigation.

It may be considered certain, that the phenomena of the passivity of iron are induced by a film of oxide or sub-oxide which on the one hand protects the iron from the attack of the acid, and on the other acts as an electro-motor, like the film of hyper-oxide of lead, which covers a platinum plate.

The constitution of this film, and the conditions under which it is formed and dissolved, are indeed questions which cannot in all cases be satisfactorily answered, yet that is not a sufficient reason for rejecting the basis of explanation alluded to above.

The formation of the oxide film in heating iron red-hot is clear. To form a similar film by immersion in a liquid, it is necessary that the requisite quantity of oxygen should be conveyed to the iron before any other chemical action of the liquid on the iron can take place.

Concentrated nitric acid is so rich in oxygen, that mere immersion of iron in it suffices to form the film. How it happens, however, that an iron wire becomes passive by repeated immersion in acid of the sp. gr. 1.35 is not yet clearly explained.

In liquids which contain less oxygen a galvanic current must sustain the communication of oxygen to the iron, in order to form the film, and thus, the electro-motive force generating the current must be the stronger the less easily oxygen can be liberated from the liquid. In nitric acid of sp. gr. 1.35, the combination of the iron wire with platinum suffices; but with dilute sulphuric acid a voltaic pile must be used.

That an iron wire which has been rendered passive by mere immersion in concentrated nitric acid, or by combination with platinum in dilute nitric acid, should exhibit its perfect metallic lustre, is no just reason for doubting the presence of a thin film of oxide in this case, for such films must, at increasing thicknesses, pass through the different shades of Newton's rings; then, so long as the film has only a thickness corresponding to the colors of the first order, it can impart to the metallic lustre of the wire, at most, only a feeble shading into blue or yellow.

In respect to the electro-motive power, the film rendering iron passive stands very near platinum.

We shall now consider briefly the explanations given by different physicists of the phenomena of passivity.

Faraday (Phil. Mag., 1836, p. 53) supposes iron to become coated with an insoluble film of oxide in concentrated nitric acid. This view was attacked on many sides, but all the facts being properly weighed in their relations, it is not possible to avoid considering this as the basis of the correct theory of passivity.

Mousson and *De la Rive* supposed that the iron was protected by a film of nitrous acid, (Pog. Ann., XXXIX, 330,) an hypothesis which Schönbein has conclusively proved to be untenable, (Pog. Ann. XXXIX, 342.) In fact, a nitrous acid film cannot be maintained as a ground of explanation of the passivity of iron, because, as we have seen, these phenomena are not limited to nitric acid.

Martens presents the view (Pog. Ann. XXXVII, 393 ; LIX, 121) that the passivity which iron assumes by heat is independent of its oxidation, the incorrectness of which Schönbein (P. A. LIX, 149,) as well as Beetz (P. A. LXII, 234), have amply shown experimentally.

Schönbein himself, who gathered most of the material for establishing a theory of passivity, and has interwoven his memoirs on this subject with various theoretical considerations, is unable to express himself decidedly in favor of any one of the explanations given above. He believes the explanation of the phenomena to be still an open question.

The views developed at the beginning of this section harmonize on essential points with those which Beetz (P. A. LXVII, 186) and Rollman (P. A. LXXIII, 406) have given. The latter has presented a new proof of the existence of an oxide film on passive iron. He has shown that rendering an iron wire passive is always attended with a diminution of its conductive capacity, which evidently can be ascribed only to a badly conducting envelope. [?]

I have finally to mention a new series of experiments which *Wetzlar* instituted twenty years after he had first made known to the chemical public the remarkable indifference which such an oxidable metal as iron exhibited in a liquid, giving up its oxygen so readily.

Wetzlar has investigated the electro-motive relation of iron treated in various ways, not with a galvanometer, but with a *condensing Bohnenberger electroscope.*

In his experiments he used plates of wrought iron and steel having a thickness of a few lines, and 2½ or 2¾ inches in diameter, and fitted to each other perfectly by well planed surfaces. The side opposite the surface of contact had in its middle a hole for receiving an insulating handle. He obtained the following results :

1. If one of two clean and bright iron or steel plates, of homogeneous character, as previously ascertained by a condenser, be rubbed with rust or polishing paper, it acts positively towards the unrubbed plate.

In this case from eight to ten contacts with the collector suffice to impart a complete charge.

2. If the contact surface of a clean steel plate be moistened with

distilled water, and the surface rubbed one or two minutes with clean blotting paper, the plate, after drying, will act negatively towards a second with which it was at first homogeneous.

3. If an iron plate be heated over a spirit-lamp to an imperceptible or invisible *iridescence*, it will act, after cooling, very strongly negative towards a plate not thus treated, so that three contacts will suffice for completely charging the condenser. Such a plate acts negatively towards copper, silver and gold.

§ 53. *Passivity of other metals.*—Other metals, especially bismuth, copper, and tin, manifest similar phenomena of passivity, though in a less marked degree than iron. Andrews (Pog. Ann. XLV, 121) made the observation that a small piece of bismuth which was immersed in a large quantity of nitric acid of the sp. gr. 1.4, and then brought into contact with a platinum plate in the liquid, almost wholly ceased to dissolve, and at the same time took on a peculiar lustre, while the same metal alone would be attacked violently by the acid.

When a small rod of bismuth was made the positive pole of a small battery of two pairs of Grove's elements, and immersed in nitric acid of the sp. gr. 1.4, its solubility was at once diminished, and upon breaking its connexion with the battery, it showed itself to be in the passive state.

The solubility of bismuth is not totally destroyed in its passive state, as is the case with passive iron ; it is only altered in degree. When it forms the positive pole of a battery, bismuth does not develop free oxygen, (Schönbein in Pog. Ann. XLIII,) as is the case with passive iron ; but it is dissolved, though slowly, if a weak battery is used ; more rapidly with a strong one.

Therefore, the protecting envelope of oxide acts similarly on bismuth as on iron, though its protecting power is less on the former.

Andrews observed the same kind of phenomena in tin and copper.

Beetz remarks (Pog. Ann. LXVII, 210,) that the reason why iron is particularly disposed to passivity is probably to be found in the great electrical difference between iron and its oxide. According to this view, a metal should exhibit the phenomena of passivity more decidedly as the electro-motive force between it and its oxide is greater.

NOTES.

(See page 323.) It might at first sight be supposed that the deflecting forces in the two positions Fig. 4 and Fig. 5, ought to be equal ; but that the deflecting force in the latter position should be double of that in the former, is explained by the fact that in the position Fig. 4, the deflecting force is determined by the difference of direction of the attracting and repelling poles of the deflecting magnet from each pole of the deflected magnet, without difference of distance ; while in the position Fig. 5, it is determined by the difference of distance of the same attracting and repelling poles from each pole of the deflected magnet, and the attraction and repulsion are inversely not as the first power, but as the second power of the distance. If they were inversely as the first power of the distance, the deflecting force in the position Fig. 5 would be the same as in the position Fig. 4.

(See page 323.) A magnet whose moment of rotation is a unit may be represented by a magnet having two poles at the unit of distance apart, each of which would attract or repel an equal pole, at the distance of a unit, with a force of a unit. Weber's unit of measure for the galvanic current may then be represented as that current, which, circulating in the circumference of a circle around a magnetic pole at the centre n of a unit of force, would have the differential of its action upon that pole expressed by the length $a\ b$ of an infinitely short element of the current when the distance $n\ a$ is a unit; or, freely expressed, the current of which a unit of length, at the distance of a unit, would act upon a unit pole with the force of a unit. Starting from this point of view, the equations of the text will be easily understood.

Let a current of a unit quantity circulate around a circle in the plane of the magnetic meridian whose radius $= r$. In this circle draw any two parallel chords, $c\ f$ and $d\ e$, at an infinitely small distance apart, and in the direction of the terrestrial magnetic force. Draw also $d\ g$ perpendicular to $c\ f$, and intersecting it in g. Let the terrestrial magnetic force be a unit. Then the force with which the element $c\ d$ of the current is urged in the direction perpendicular to the plane of the circle is expressed by the perpendicular distance $d\ g$ of the chords; that is, the same as the force with which it would be acted upon by a unit magnetic pole placed at the distance of a unit in the direction of the chords. The element $e\ f$ is urged with an equal force in the opposite direction. The moment of rotation impressed by these two forces will, therefore, be $d\ g \times d\ e =$ area $c\ d\ e\ f$. Consequently, the moment of rotation of the whole circular current is expressed by the area of the circle. And if the current be of the quantity g, the moment of rotation will be

$$G = \text{area} \times g = \pi\ r^2\ g.$$

Now, in the tangent compass the deflecting force of the circle, or ring, may be represented by the force with which the circle would act upon a single unit pole at its centre n. The element of this force for an infinitely short part, $a\ b$, of the circumference, when the current is of the quantity g, is $\frac{a\ b}{r^2} g$, and the whole force is, therefore, $\frac{2\ \pi\ g}{r}$; and T tan. w is the value of this force as given by the tangent compass, or $\frac{2\ \pi\ g}{r} = \text{T tan. } w$.

(See page 362.) It will readily be seen that $a + \frac{1}{a}$ is always greater than 2, except when $a = 1$, by substituting for a, successively, the values 2, 3, 4, &c., or $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, &c.

The proposition may also be easily demonstrated. To express it in general terms, let $a = \frac{r}{s}$, r and s being any positive whole numbers.

Then: $$a + \frac{1}{a} = \frac{r}{s} + \frac{r}{s};$$

Suppose $s > r$ and $= r + t$, then—

$$\frac{r}{s} + \frac{s}{r} = \frac{r}{r+t} + \frac{r+t}{r} = \frac{r}{r+t} + \frac{t}{r} + 1.$$

$$= 1 + \frac{r^2 + rt + t^2}{r\,(r+t)}$$

$$= 1 + \frac{(r+t)^2 - rt}{r\,(r+t)}$$

$$= 1 + \frac{r+t}{r} - \frac{t}{r+t}$$

$$= 1 + 1 + \frac{t}{r} - \frac{t}{r+t}$$

$$= 2 + t\left(\frac{1}{r} - \frac{1}{r+t}\right)$$

But since $r + t$ is greater than r, the expression in the last brackets must be positive, and therefore $\frac{r}{s} + \frac{s}{r}$ greater than 2. But $\frac{r}{s} + \frac{s}{r}$ is only a general form for the expression $a + \frac{1}{a}$, consequently $a + \frac{1}{a}$ is always greater than 2.

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ERRATA.

On page 299, Prof. Guyot's measurement of MOUNT MITCHELL should be 6,578 feet, and of CLINGMAN'S PEAK 6,702 feet.