ANNUAL REPORT

OF THE

BOARD OF REGENTS

OF THE

SMITHSONIAN INSTITUTION,

SHOWING

THE OPERATIONS, EXPENDITURES, AND CONDITION OF THE INSTITUTION

FOR

THE YEAR ENDING JUNE 30, 1898.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1899.

LETTER

FROM THE

SECRETARY OF THE SMITHSONIAN INSTITUTION,

ACCOMPANYING

The Annual Report of the Board of Regents of the Institution for the year ending June 30, 1898.

SMITHSONIAN INSTITUTION,
Washington, D. C., March 4, 1899.

To the Congress of the United States:

In accordance with section 5593 of the Revised Statutes of the United States, I have the honor, in behalf of the Board of Regents, to submit to Congress the Annual Report of the operations, expenditures, and condition of the Smithsonian Institution for the year ending June 30, 1898.

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

S. P. LANGLEY,
Secretary of Smithsonian Institution.

Hon. GARRET A. HOBART,
President of the Senate.

ANNUAL REPORT OF THE SMITHSONIAN INSTITUTION FOR THE YEAR ENDING JUNE 30, 1898.

SUBJECTS.

1. Proceedings of the Board of Regents for the session of January, 1898.

2. Report of the Executive Committee, exhibiting the financial affairs of the Institution, including a statement of the Smithson fund, and receipts and expenditures for the year ending June 30, 1898.

3. Annual report of the Secretary, giving an account of the operations and condition of the Institution for the year ending June 30, 1898, with statistics of exchanges, etc.

4. General appendix, comprising a selection of miscellaneous memoirs of interest to collaborators and correspondents of the Institution, teachers, and others engaged in the promotion of knowledge. These memoirs relate chiefly to the calendar year 1898.

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THE SMITHSONIAN INSTITUTION.

MEMBERS EX OFFICIO OF THE "ESTABLISHMENT."

WILLIAM MCKINLEY, President of the United States.
GARRET A. HOBART, Vice-President of the United States.
MELVILLE W. FULLER, Chief Justice of the United States.
WILLIAM R. DAY, Secretary of State.
LYMAN J. GAGE, Secretary of the Treasury.
RUSSELL A. ALGER, Secretary of War.
JOHN W. GRIGGS, Attorney-General.
CHARLES EMORY SMITH, Postmaster-General.
JOHN D. LONG, Secretary of the Navy.
CORNELIUS N. BLISS, Secretary of the Interior.
JAMES WILSON, Secretary of Agriculture.

REGENTS OF THE INSTITUTION.

(List given on the following page.)

OFFICERS OF THE INSTITUTION.

SAMUEL P. LANGLEY, *Secretary,*

Director of the Institution and of the U. S. National Museum.

RICHARD RATHBUN, *Assistant Secretary,*

In charge of Office and Exchanges.

CHARLES D. WALCOTT, *Acting Assistant Secretary,*

In charge of National Museum.

REGENTS OF THE SMITHSONIAN INSTITUTION.

By the organizing act approved August 10, 1846 (Revised Statutes, Title LXXIII, section 5580), and amended March 12, 1894, "The business of the institution shall be conducted at the city of Washington by a Board of Regents, named the Regents of the Smithsonian Institution, to be composed of the Vice-President, the Chief Justice of the United States, three members of the Senate, and three members of the House of Representatives, together with six other persons, other than Members of Congress, two of whom shall be resident in the city of Washington and the other four shall be inhabitants of some State, but no two of the same State."

REGENTS FOR THE YEAR ENDING JUNE 30, 1898.

The Chief Justice of the United States:
  MELVILLE W. FULLER, elected Chancellor and President of the Board January 9, 1889.

The Vice-President of the United States:
  GARRET A. HOBART (March 4, 1897).

	Term expires.
United States Senators:	
JUSTIN S. MORRILL (appointed Feb. 21, 1883, Mar. 23, 1885, Dec. 15, 1891, and Mar. 15, 1897)	Mar. 3, 1903
SHELBY M. CULLOM (appointed Mar. 23, 1885, Mar. 28, 1889, and Dec. 18, 1895)	Mar. 3, 1901
GEORGE GRAY (appointed Dec. 20, 1892, and Mar. 20, 1893)	Mar. 3, 1899
Members of the House of Representatives:	
JOSEPH WHEELER (appointed Jan. 10, 1888, Jan. 6, 1890, Jan. 15, 1892, Jan. 4, 1894, Dec. 20, 1895, and Dec. 22, 1897)	Dec. 22, 1899
ROBERT R. HITT (appointed Aug. 11, 1893, Jan. 4, 1894, Dec. 20, 1895, and Dec. 22, 1897)	Dec. 22, 1899
ROBERT ADAMS, Jr. (appointed Dec. 20, 1895, and Dec. 22, 1897)	Dec. 22, 1899
Citizens of a State:	
JAMES B. ANGELL, of Michigan (appointed Jan. 19, 1887, and Jan. 9, 1893)	Jan. 19, 1899
ANDREW D. WHITE, of New York (appointed Feb. 15, 1888, and Mar. 19, 1894)	Mar. 19, 1900
WILLIAM PRESTON JOHNSTON, of Louisiana (appointed Jan. 26, 1892, and Jan. 24, 1898)	Jan. 24, 1904
Citizens of Washington:	
JOHN B. HENDERSON (appointed Jan. 26, 1892, and Jan. 24, 1898)	Jan. 24, 1904
GARDINER G. HUBBARD (appointed Feb. 27, 1895), died Dec. 11, 1897.	
WILLIAM L. WILSON (appointed Jan. 14, 1896)	Jan. 14, 1902
ALEXANDER GRAHAM BELL (appointed Jan. 24, 1898)	Jan. 24, 1904

Executive Committee of the Board of Regents.

J. B. Henderson, *Chairman*. William L. Wilson. Gardiner G. Hubbard.
Alexander Graham Bell (from Jan. 26, 1898).

PROCEEDINGS OF THE BOARD OF REGENTS OF THE SMITHSONIAN INSTITUTION,

At the Annual Meeting Held January 26, 1898.

In accordance with the resolution of the Board of Regents adopted January 8, 1890, by which its stated annual meeting occurs on the fourth Wednesday of January, the Board met to-day at 10 o'clock a. m.

Present: The Chancellor (Mr. Chief Justice Fuller), in the chair; the Hon. Garret A. Hobart, Vice President of the United States; the Hon. J. S. Morrill; the Hon. George Gray; the Hon. Joseph Wheeler; the Hon. R. R. Hitt; the Hon. Robert Adams, jr.; the Hon. William L. Wilson; the Hon. J. B. Henderson; the Hon. Alexander Graham Bell; and the Secretary, Mr. S. P. Langley.

Excuses for nonattendance were presented from Senator Cullom and Dr. William Preston Johnston.

At the Chancellor's suggestion, the Secretary read the minutes of the last meeting in abstract.

The Chancellor said, in relation to the matter of the appointment of an Acting Secretary, that he had found that his predecessor, when he made an appointment of this kind, occasionally, he could not say always, reported it to the Board, and as he had made an appointment of an Acting Secretary last May, he would read its terms as a report to the Board:

Whereas it has been signified to the undersigned, Chancellor of the Smithsonian Institution, that the contingency of the inability of the Secretary of the Smithsonian Institution to discharge the duties of that office is about to arise, by reason of his absence from the United States;

Now, therefore, by the authority conferred on me by the act of Congress entitled "An act to provide for the appointment of an Acting Secretary of the Smithsonian Institution," approved May 13, 1884 (23 Stat., 21), I hereby appoint Mr. Richard Rathbun an Assistant Secretary of the Institution, to act as Secretary of the Smithsonian Institution during the inability of the Secretary to perform its duties.

Given under my hand at Washington, D. C., this 22d day of May, A. D. 1897.

Melville W. Fuller,
Chancellor of the Smithsonian Institution.

There being no further remarks, the Chancellor declared the minutes approved.

The Secretary said that he had the sad duty to officially announce the death of Mr. Gardiner G. Hubbard, a late resident Regent of the Institution.

Mr. Wilson then offered the following resolutions:

Whereas the Hon. Gardiner Greene Hubbard, a citizen Regent and a member of the Executive Committee of the Smithsonian Institution, died at his residence in this city on the 11th day of December, 1897;

Resolved, That the Regents of the Institution place upon their records this testimonial of their respect and admiration for Mr. Hubbard, as a singularly public-spirited citizen, an ever-generous promoter of education, and active patron of scientific work; and this expression of their sincere regret for the loss of a colleague and friend, whose life was adorned by so many personal virtues and whose association with them has left so many endearing memories.

Resolved, That a copy of this minute be engrossed and transmitted to the family of Mr. Hubbard.

General Wheeler said that Mr. Hubbard had impressed him so favorably by his public spirit and by the great good he had done, that he considered his death a loss not only to this Institution and to his friends, but to the entire country.

On motion the resolutions were adopted by a rising vote.

The Secretary announced the appointment and reappointment of Regents as follows:

Senator Justin S. Morrill reappointed by the Vice-President on March 15, 1897.

Mr. Joseph Wheeler, Mr. R. R. Hitt, and Mr. Robert Adams, jr., reaped by the Speaker on December 22, 1897.

Mr. J. B. Henderson and Dr. William Preston Johnston reappointed by joint resolution of January 24, 1898.

Mr. Alexander Graham Bell appointed to the vacancy caused by Mr. Hubbard's death, by joint resolution of January 24, 1898.

The Chancellor stated that certain vacancies existed on the Executive Committee.

Mr. Adams moved—

That Mr. Henderson be reelected Chairman of the Executive Committee.

Carried.

General Wheeler moved—

That Mr. Alexander Graham Bell be elected to fill the vacancy on the Executive Committee caused by the death of Mr. Hubbard.

Carried.

The Secretary presented his annual report of the operations of the Institution for the fiscal year ending June 30, 1897, stating that there was very little to say in addition to the printed report, which he hoped was self-explanatory, though he might add that he did not think there had been any time in the history of the Institution when it had given more gratifying evidence of its importance and growth. What it had done in the way of publication during this period could be seen by a glance at the table upon which the numerous new volumes were placed for scrutiny.

On motion the report was accepted.

Senator Henderson presented the report of the Executive Committee and explained that it brought the financial matters of the Institution up to the 30th of June last.

On motion the report was adopted.

Senator Henderson introduced the customary resolution relative to income and expenditure, which was adopted as follows:

Resolved, That the income of the Institution for the fiscal year ending June 30, 1899, be appropriated for the service of the Institution, to be expended by the Secretary with the advice of the Executive Committee, with full discretion on the part of the Secretary as to items.

Senator Henderson, on behalf of the Permanent Committee, stated that he had made a report at the last annual meeting on the condition of the affairs of the Hodgkins and Avery Bequests, and that there was very little to add to it.

In regard to the Hodgkins fund, Dr. M. L. Chambers, the Executor of Mr. Hodgkins, had lately requested to be relieved of his trust in connection with the estate. He still held the proceeds of two mortgage notes amounting to about $10,000, having received notice that he would be held responsible upon a warranty given by Mr. Hodgkins to Edward Smith, of the title of certain premises in New York City. The case was then pending in the Court of Appeals, and was expected to come up for trial soon. Everything was going along properly and the Chairman hoped that at the next annual meeting he would be in a position to make a report of the entire disposition of the property.

Concerning the Avery bequest, Senator Henderson said that Robert Stanton Avery, who died at Washington on September 12, 1894, left the bulk of his property to the Smithsonian Institution. His will was probated February 2, 1895, the executrix had filed a first account, and the estate was now nearly administered upon.

The personal estate was invested in Northern Pacific Railroad bonds, which had to be sold at a very great discount on their face value. The Institution was now in possession of five pieces of real estate and four houses, located in northeast and southeast Washington. One of these, the home of the testator, had been occupied since his death by the executrix, Miss Avery, at a small rent. This property had been valued by experts employed by the Institution at $4,750. Miss Avery offered for it $4,500, the same to be set off against an allowance of $4,500 for her services to her late uncle during his illness. Although this offer was $250 less than the expert valuation, all things considered it seemed a wise course to accept it, and this had lately been done.

One of the pieces of property stood in the name of the testator's wife, but his will expressly stated that he furnished the money for its purchase, and the property was his. The Institution filed a bill in equity to enjoin the heirs at law of Mrs. Avery from asserting ownership. In the Equity Court the prayer of the bill was granted. The Court of Appeals reversed this decision, and the Institution carried the case to the Supreme Court of the United States, where it was argued on the 12th instant.

The entire property, provided the suit in the Supreme Court was favorably decided, would amount to about $30,000; otherwise, to about $24,000. The houses were in good condition, and were bringing a fair rental.

Miss Avery had presented a claim of $6,000 as compensation for the very trying duties she had to perform in the care of her uncle. She prosecuted her suit before the Probate Court, and the Permanent Committee had come to the conclusion, when the facts were presented, that it would be better that she should be settled with than to go to a jury, and they compromised on a settlement of $4,500. She now offered to take the property at that figure in lieu of the money, and the Committee thought it was advisable to accept the offer; but the attorney recently called attention to the fact that there was a doubt as to the conveyance and the making of deeds by the Institution.

It seemed to him (Senator Henderson) that if the Institution were authorized to hold property, it should certainly also by some means be authorized to convey or exchange this property. The rental of this particular piece did not much more than pay taxes and it was considered desirable to get rid of it. In order to meet the difficulty as to conveyance, he would offer the following resolution, expressing the opinion that it was the best arrangement that could be made:

Resolved by the Board of Regents, That the Secretary of the Smithsonian Institution is authorized and empowered to sell and convey, on such terms as may seem to him most beneficial to the Institution, any and all lands, town lots, and improvements thereon, which were devised or conveyed to said institution by R. S. Avery, deceased.

And in the execution of the power hereby conferred on him, the Secretary shall execute to the vendees, respectively, written conveyances signed and acknowledged by himself as Secretary aforesaid, and attested by the seal of the Smithsonian Institution.

Senator Henderson stated that this covered the matters under the charge of the Permanent Committee, except one of minor importance, which had already been before the Board, namely, the question as to whether Congress should be asked to remit taxes on real estate belonging to the Institution.

The Chancellor said that three matters were under consideration:

1. In regard to the report. On motion, the report was accepted.

2. On the adoption of the resolution with regard to conveying real estate. On motion, the resolution was adopted.

3. A general discussion then ensued in regard to the exemption from taxation of the Avery property, and while no formal action was taken, the prevailing opinion was that it was better to pay the taxes than to ask exemption of Congress.

The Secretary announced his acceptance of the resignation of Prof. Charles D. Walcott as Acting Assistant Secretary in Charge of the National Museum, to take effect on July 1, 1898, and requested the authority of the Board to transfer to that position, if it seemed best for the Museum's interests, the present Assistant Secretary in Charge of Office and Exchanges, Mr. Richard Rathbun. The Board then adopted the following resolution:

Resolved, That the restriction placed upon the duties of Mr. Richard Rathbun by the terms of his appointment, approved by the Board on February 1, 1897, be removed, to permit of his assignment by the Secretary to such duty as he may deem best for the interests of the Institution; this to take effect not before July 1, 1898.

The Secretary asked authority to use a portion of the accrued interest of the Hodgkins Fund in connection with his experiments in mechanical flight. After discussion the Board adopted the following resolution:

That the Board authorize any expenditures hereafter to be made from the income of the Hodgkins Fund, having the approval of the Executive Committee, in regard to the expenses of certain experiments being conducted by the Secretary in mechanical flight; and that a report of these expenditures shall be submitted to the Board at its next annual meeting.

The question being put, the motion was carried.

The Secretary said:

I explained last year to the Board the great difficulties which the Civil Service rules introduced in making an appointment to the scientific bureaus of the Institution, and I again ask their attention to the letter of their colleague, Dr. Wilson, then Postmaster-General, which I submitted to them at that time, as follows:

"OFFICE OF POSTMASTER-GENERAL,
" *Washington, D. C., January 25, 1897.*

"DEAR PROFESSOR LANGLEY: I submitted to the President the letter you gave me. He seemed favorably inclined to your suggestion that the Assistant Secretary and the four heads of bureaus should be excepted, and retained the letter, saying that he would at once send it to the Civil Service Commission for that purpose. Unless the Commission, therefore, make some adverse report, substantial enough to arrest his inclination, I think the exception will be made.

"Yours, truly, W. L. WILSON.

"Prof. S. P. LANGLEY."

I have twice urged upon the Commission the desirability of making this exception, but they have not done so, though the head of the Commission expresses a willingness to go with me to the President in asking him to make any specific exception to some specific name, but this is not what the late President of the United States (as interpreted by the late Postmaster-General) meant, for the President recognized, when the subject was brought to his attention, that it was probably a very difficult matter to get any man who was competent to take one of those positions, and especially that of the Assistant Secretary in Charge of the Museum, to stand an examination. Since this, an additional year's experience has led me to feel that I may yet be glad to see excepted, if not all positions in the Bureaus under the Board's control, then at least all scientific positions under them. I desire the instructions of the Board on this point.

After some discussion, the following resolution was adopted:

Resolved, That the Secretary be instructed to request of the President such a modification of the Civil Service regulations relating to appointments as will permit an exemption of such scientific positions under the Smithsonian Institution as the Secretary may deem best for the interests of the Institution.

The report of a special committee, of which Mr. Hubbard had been chairman, was submitted by Senator Henderson, pointing out the need for the National Museum of a new building, as well as an increase in the scientific staff and a definite purchasing fund; for the Bureau of American Ethnology the desirability of the passage of a law declaring archæological sites on the public domain public monuments; and for the National Zoological Park the need of greater facilities for the purchase and housing of animals.

There was also a further suggestion of the form which the reports of bureau officers on the property in their charge should assume.

Mr. Hitt moved—

That the report of the special committee be accepted and the committee be discharged.

Carried.

Senator Morrill here said:

As some of you know, I have been urging a new museum building for about ten years. The bills I have introduced have passed through the Senate several times, but never through the House. I may say now that I shall not live long enough to get the measure completed. It was heretofore contemplated that there should be a Museum building on the west of the Smithsonian building, in a position corresponding with the present Museum building, and these two were to be connected by a building on B street, thus making the largest museum in the country. I have now about decided to abandon that plan and try to secure the building on B street first. I merely state this in order to ascertain whether the change of plan is favored by the Board of Regents.

It was moved—

That the Board approve the suggestion made by Senator Morrill in regard to a new building for the National Museum.

Seconded and carried.

There being no further business to come before the Board, on motion it adjourned.

REPORT OF THE EXECUTIVE COMMITTEE OF THE BOARD OF REGENTS OF THE SMITHSONIAN INSTITUTION

FOR THE YEAR ENDING JUNE 30, 1898.

To the Board of Regents of the Smithsonian Institution:

Your Executive Committee respectfully submits the following report in relation to the funds of the Institution, the appropriations by Congress, and the receipts and expenditures for the Smithsonian Institution, the U. S. National Museum, the International Exchanges, the Bureau of Ethnology, the National Zoological Park, and the Astrophysical Observatory for the year ending June 30, 1898, and balances of former years:

SMITHSONIAN INSTITUTION.

Condition of the Fund July 1, 1898.

The amount of the bequest of James Smithson deposited in the Treasury of the United States, according to act of Congress of August 10, 1846, was $515,169. To this was added by authority of Congress, February 8, 1867, the residuary legacy of Smithson, savings from income and other sources, to the amount of $134,831.

To this also have been added a bequest from James Hamilton, of Pennsylvania, of $1,000; a bequest of Dr. Simeon Habel, of New York, of $500; the proceeds of the sale of Virginia bonds, $51,500; a gift from Thomas G. Hodgkins, of New York, of $200,000 and $8,000, being a portion of the residuary legacy of Thomas G. Hodgkins, and $1,000, the accumulated interest on the Hamilton bequest, making in all, as the permanent fund, $912,000.

The Institution also holds the additional sum of $42,000, received upon the death of Thomas G. Hodgkins, in registered West Shore Railroad 4 per cent bonds, which were, by order of this Committee, under date of May 18, 1894, placed in the hands of the Secretary of the Institution, to be held by him subject to the conditions of said order.

Statement of the Receipts and Expenditures from July 1, 1897, to June 30, 1898.

RECEIPTS.

Cash on hand July 1, 1897		$61,532.50	
Interest on fund July 1, 1897	$27,360.00		
Iuterest on fuud January 1, 1898	27,360.00		
		54,720.00	
Interest to January 1, 1898, on West Shore bonds		1,680.00	
			$117,932.50
Cash from sales of publications		458.08	
Cash from repayments, freight, etc		10,320.14	
			10,778.22
Total receipts			128,710.72

EXPENDITURES.

Building:			
Repairs, care, and improvements	$3,065.30		
Furuiture and fixtures	79.89		
		$3,145.19	
General expenses:			
Postage and telegraph	222.22		
Stationery	1,311.29		
General printing	93.50		
Incidentals (fuel, gas, etc.)	5,320.53		
Library (books, periodicals, etc.)	3,305.96		
Salaries [1]	22,309.44		
Gallery of Art	11.25		
Meetings	110.77		
		32,684.96	
Publications and researches:			
Smithsonian contributions	751.82		
Miscellaueous collections	4,085.95		
Reports	1,141.79		
Special publications	9,678.03		
Researches	3,444.17		
Apparatus	27.76		
Hodgkins fund	2,917.68		
Explorations	450.00		
		22,497.20	
Literary and scientific exchanges		4,580.35	
			62,907.70
Balauce unexpended June 30, 1898			65,803.02

The cash received from the sale of publications, from repayments for freights, etc., is to be credited to the items of expenditure as follows:

Smithsonian contributions	$106.36	
Miscellaueous collections	334.72	
Reports	17.00	
		$458.08

[1] In additiou to the above $22,309.44 paid for salaries under general expenses, $7,434.57 were paid for services, viz: $1,970.88 charged to building account, $949.18 to Hodgkins fund account, $1,766.76 to library account, and $2,747.75 to researches account.

Hodgkins fund	$361.59
Exchanges	6,193.53
Incidentals	3,015.02
Explorations	750.00
Total	10,778.22

The net expenditures of the Institution for the year ending June 30, 1898, were therefore $52,129.48, or $10,778.22 less than the gross expenditures, $62,907.70, as above stated.

All moneys received by the Smithsonian Institution from interest, sales, refunding of moneys temporarily advanced, or otherwise, are deposited with the Treasurer of the United States to the credit of the Secretary of the Institution, and all payments are made by his checks on the Treasurer of the United States.

Your committee also presents the following statements in regard to appropriations and expenditures for objects intrusted by Congress to the care of the Smithsonian Institution:

Detailed statement of disbursements from appropriations committed by Congress to the care of the Smithsonian Institution for the fiscal year ending June 30, 1898, and from balances of former years.

INTERNATIONAL EXCHANGES, 1898.

RECEIPTS.

Appropriated by Congress for the fiscal year ending June 30, 1898, "for expenses of the system of international exchanges between the United States and foreign countries, under the direction of the Smithsonian Institution, including salaries or compensation of all necessary employees," (sundry civil act, June 4, 1897) ... $19,000.00

DISBURSEMENTS.

(From July 1, 1897, to June 30, 1898.)

Salaries or compensation:

1 curator, 12 months, at $225	$2,700.00
1 chief clerk, 12 months, at $175	2,100.00
1 clerk, 12 months, at $130	1,560.00
1 clerk, 12 months, at $100	1,200.00
1 clerk, 12 months, at $85	1,020.00
1 clerk, 6 months, at $75; 6 months, at $80	930.00
1 clerk, 8 months and 3 days, at $70	566.77
1 clerk, 2 months, at $100	200.00
1 copyist, 11 months, at $45	495.00
1 stenographer, 6 months, at $60; 6 months, at $75	810.00
1 packer, 10½ months, at $55	577.50
1 copyist, 6 months, at $35; 6 months, at $45	480.00
1 messenger, 10 months and 9 days, at $25	257.25
1 messenger, one-half month and 27½ days, at $25	34.87
1 messenger, 8 days, at $25 per month	6.66
1 workman, 313 days, at $1.50	469.50
1 laborer, 313 days, at $1.50	469.50
1 cleaner, 154 days, at $1	154.00
1 carpenter, 29½ days, at $3	88.50

Salaries or compensation—Continued.

1 carpenter, 2 days, at $3		$6.00	
1 painter, 4 days, at $2		8.00	
1 agent, 12 months, at $50		600.00	
1 agent, 12 months, at $91.66⅔		1,100.00	
Total salaries or compensation		15,833.55	
General expenses:			
Freight	$2,187.81		
Postage and telegraph	120.00		
Stationery and supplies	164.23		
Packing boxes	633.80		
Traveling expenses	20.45		
		3,126.29	
Total disbursements			$18,959.84
Balance July 1, 1898, to meet liabilities			40.16

INTERNATIONAL EXCHANGES, 1897.

Balance July 1, 1897, as per last report		$179.63

DISBURSEMENTS.

Freight	$147.19	
Postage and telegraph	1.01	
Stationery and supplies	30.35	
		178.55
Balance July 1, 1898		1.08

INTERNATIONAL EXCHANGES, 1896.

Balance July 1, 1897, as per last report $0.03

Balance carried, under the provisions of the Revised Statutes, section 3090, by the Treasury Department to the credit of the surplus fund June 30, 1898.

AMERICAN ETHNOLOGY, 1898.

RECEIPTS.

Appropriation by Congress for the fiscal year ending June 30, 1898, "for continuing ethnological researches among the American Indians, under the direction of the Smithsonian Institution, including salaries or compensation of all necessary employees, $45,000, of which sum not exceeding $1,000 may be used for rent of building" (sundry civil act, June 4, 1897) $45,000.00

The actual conduct of these investigations has been continued by the Secretary in the hands of Maj. J. W. Powell, director of the Bureau of American Ethnology.

DISBURSEMENTS.

(July 1, 1897, to June 30, 1898.)

Salaries or compensation:

1 director, 12 months, at $375	$4,500.00
1 ethnologist in charge, 12 months, at $325	3,900.00
1 ethnologist, 12 months, at $200	2,400.00
1 ethnologist, 12 months, at $166.67	2,000.04
1 ethnologist, 12 months, at $166.67	2,000.04
1 ethnologist, 12 months, at $166.67	2,000.04

Salaries or compensation—Continued.			
1 ethnologist, 11 months and 10 days, at $150		$1,700.00	
1 ethnologist, 12 months, at $125		1,500.00	
1 ethnologist, 12 months, at $125		1,500.00	
1 ethnologist, 12 months, at $125		1,500.00	
1 illustrator, 8½ months and 2 days, at $100		856.45	
1 custodian, 8 months, at $100		800.00	
1 clerk, 12 months, at $100		1,200.00	
1 clerk, 12 months, at $100		1,200.00	
1 clerk, 3 months, at $100		300.00	
1 clerk, 12 months, at $75		900.00	
1 clerk, 12 months, at $75		900.00	
1 copyist, 12 months, at $50		600.00	
1 messenger, 1 month		60.00	
1 messenger, 12 months, at $50		600.00	
1 skilled laborer, 10½ months, at $60		630.00	
1 skilled laborer, 12 months, at $45		540.00	
1 laborer, 75 days, at $1.50; 60 days, at $2, and 6 months, at $50		532.50	
1 laborer, 141 days, at $1.50		211.50	
Total salaries or compensation		32,330.57	
General expenses:			
Drawings and illustrations	$805.30		
Freight	123.16		
Postage, telegrams, etc	88.75		
Publications	1,205.28		
Office furniture	400.90		
Rental	999.96		
Reports	175.20		
Special services	1,526.09		
Specimens	482.22		
Books	767.36		
Stationery	163.44		
Supplies	1,126.23		
Traveling and field expenses	2,750.71		
Miscellaneous	223.55		
		10,838.15	
Total disbursements			$43,168.72
Balance July 1, 1898, to meet liabilities			1,831.28

NORTH AMERICAN ETHNOLOGY, 1897.

Balance July 1, 1897, as per last report	$218.04

DISBURSEMENTS.

General expenses:		
Books	$5.00	
Freight	31.70	
Furniture	7.50	
Miscellaneous	3.26	
Specimens	25.00	
Traveling expenses	140.00	
Total		212.46
Balance July 1, 1898		5.58

NORTH AMERICAN ETHNOLOGY, 1896.

Balance July 1, 1897, as per last report $56.52

Balance carried, under the provisions of Revised Statutes, section 3090, by the Treasury Department to the credit of the surplus fund, June 30, 1898.

NATIONAL MUSEUM.—PRESERVATION OF COLLECTIONS, 1898.

RECEIPTS.

Appropriation by Congress for the fiscal year ending June 30, 1898, "for continuing the preservation, exhibition, and increase of the collections from the surveying and exploring expeditions of the Government and from other sources, including salaries or compensation of all necessary employees, $160,000, of which sum $3,500 may be used for necessary drawings and illustrations for publications of the National Museum" (sundry civil act, June 4, 1897) $160,000.00

EXPENDITURES.

Services	$139,588.68		
Special services	4,577.72		
Total services		$144,166.40	
Miscellaneous:			
Supplies	$3,908.35		
Stationery	854.23		
Specimens	3,867.42		
Books	833.80		
Travel	2,421.46		
Freight	1,584.83		
Total miscellaneous		13,470.09	
Total expenditures			157,636.49
Balance July 1, 1898, to meet outstanding liabilities			2,363.51

Analysis of expenditure for salaries or compensation.

SCIENTIFIC STAFF.

1 executive curator, 12 months, at $291.66	$3,499.92
1 curator, 6 months, at $250; 6 months, at $291.66	3,249.96
1 curator, 9 months, at $291.66	2,624.94
1 curator, 12 months, at $200	2,400.00
1 curator, 12 months, at $200	2,400.00
1 curator, 10 months, at $208.33	2,083.30
1 curator, 2 months, at $167; 6 months, at $200	1,534.00
1 curator, 12 months, at $175	2,100.00
1 curator, 26 days, at $150	125.81
1 acting curator, 5 months, at $150	750.00
1 assistant curator, 12 months, at $150	1,800.00
1 assistant curator, 12 months, at $150	1,800.00
1 assistant curator, 12 months, at $150	1,800.00
1 assistant curator, 12 months, at $133.33	1,599.96
1 assistant curator, 12 months, at $133.33	1,599.96
1 assistant curator, 12 months, at $130	1,560.00
1 assistant curator, 12 months, at $125	1,500.00

1 assistant curator, 4 months 14 days, at $125	$562.50	
1 assistant curator, 12 months, at $166.66	1,399.92	
1 assistant curator, 12 months, at $100	1,200.00	
1 second assistant curator, 12 months, at $80	960.00	
1 aid, 12 months, at $100	1,200.00	
1 aid, 12 months, at $100	1,200.00	
1 aid, 12 months, at $80	960.00	
1 aid, 12 months, at $60	720.00	
1 aid, 12 months, at $50	600.00	
1 aid, 6 months 15 days, at $50	324.19	
1 aid one half month, at $50, $25; 16 days, at $50, $25.81; 2 months 22 days, at $50, $137.38; 15 days, at $50, $24.19	212.38	
1 assistant, 43 days, at $60; 1 month, at $75	161.13	
		$41,927.97

PREPARATORS.

1 photographer, 12 months, at $158.33	1,899.96	
1 modeler, 10 months 14 days, at $100	1,050.00	
1 osteologist, 12 months, at $90	1,080.00	
1 preparator, 12 months, at $80	960.00	
1 preparator, 12 months, at $80	960.00	
1 preparator, 10 months 30 days, at $80	881.29	
1 preparator, 12 months, at $60	720.00	
1 preparator, 10 months 30 days, at $60	658.06	
1 preparator, 1 month, at $110; 9 months 32 days, at $50	612.20	
1 preparator, 9 months 26 days, at $60	594.00	
1 preparator, 12 months, at $45	540.00	
1 preparator, 10 months, 49½ days, at $45	521.86	
1 preparator, 49 days, at $3.20, $156.80; 13 days, at $3.20, $41.60	198.40	
1 taxidermist, 12 months, at $90	1,080.00	
1 taxidermist, 9 months, 30 days, at $100	1,001.61	
1 taxidermist, 11 months, 14 days, at $60	690.00	
		13,447.38

CLERICAL STAFF.

1 chief clerk, 12 months, at $208.33	2,500.00	
1 acting chief clerk, 12 months, at $150	1,800.00	
1 editor, 12 months, at $167	2,004.00	
1 chief of division, 12 months, at $200	2,400.00	
1 registrar, 12 months, at $167	2,004.00	
1 disbursing clerk, 12 months, at $116.67	1,400.04	
1 finance clerk, 12 months, at $110	1,320.00	
1 assistant librarian, 12 months, at $117	1,404.00	
1 property clerk, 6 months, at $115	690.00	
1 acting property clerk, 6 months, at $40	240.00	
1 stenographer, 12 months, at $100	1,200.00	
1 stenographer, 12 months, at $50	600.00	
1 stenographer, 6 months 12 days, at $75	479.03	
1 stenographer, 2 months 17 days, at $50	127.42	
1 stenographer, 20 days, at $50, $33.33; 30 days, at $50, $48.49; 2 months 11 days, at $50, $117.74	199.56	
1 stenographer, 1 month 20 days, at $50, $83.33; 10½ days, at $50, $17.50; 31 days, at $50, $50.54	151.37	
1 stenographer, 11 days, at $50	18.33	
1 stenographer, 6 months, at $45	270.00	
1 stenographer, 6 months, at $45	270.00	

1 typewriter, 5 months, at $50; 7 months, at $75	$775.00	
1 typewriter, 12 months, at $50	600.00	
1 typewriter, 3 months 13 days, at $50	170.97	
1 typewriter, 2 months, at $50, $100; 18 days, at $50, $29.03; 4 days, at $50, $6.45	135.48	
1 clerk, 12 months, at $83.34	1,000.08	
1 clerk, 12 months, at $60	720.00	
1 clerk, 12 months, at $90	1,080.00	
1 clerk, 11 months 28 days, at $55	656.33	
1 clerk, 12 months, at $55	660.00	
1 clerk, 12 months, at $60	720.00	
1 clerk, 12 months, at $50	600.00	
1 clerk, 19 days, at $55	33.70	
1 clerk, 12 months, at $115	1,380.00	
1 clerk, 12 months, at $70	840.00	
1 clerk, 12 months, at $55	660.00	
1 clerk, 12 months, at $50	600.00	
1 clerk, 8 months 6 days, at $50	410.00	
1 clerk, 12 months, at $50	600.00	
1 clerk, 12 months, at $75	900.00	
1 clerk, 12 months, at $50	600.00	
1 clerk, 12 months, at $50	600.00	
1 clerk, 12 months, at $70	840.00	
1 clerk, 6 days, at $50, $10; 7 months 30 days, at $50, $400.81	410.81	
1 clerk, 12 months, at $115	1,380.00	
1 clerk, 6 months 17 days, at $50	327.42	
1 clerk and typewriter, 12 months, at $75	900.00	
1 clerk, 6 months, at $100	600.00	
1 clerk, 12 months, at $50	600.00	
1 clerk, 12 months, at $90	1,080.00	
1 clerk and preparator, 12 months, at $45	540.00	
1 copyist, 12 months, at $35	420.00	
1 copyist, 2 months, at $45	90.00	
1 copyist, 12 months, at $30	360.00	
1 copyist, 12 months, at $50	600.00	
1 copyist, 12 months, at $55	660.00	
1 copyist, 12 months, at $50	600.00	
1 copyist, 1 month, at $40	40.00	
1 copyist, 2 months, at $30	60.00	
1 copyist, 12 months, at $40	480.00	
1 copyist, 2 months, at $40, $80; 5 months, at $40, $200	280.00	
1 copyist, 12 months, at $35	420.00	
1 copyist, 12 months, at $35	420.00	
1 copyist, 12 months, at $35	420.00	
1 copyist, 12 months, at $50	600.00	
1 copyist, 12 months, at $30	360.00	
1 copyist, 2 months, at $30	60.00	
		$45,367.54

BUILDINGS AND LABOR.

1 general foreman, 12 months, at $115	1,380.00
1 foreman, 12 months, at $50	600.00
1 chief of watch, 12 months, at $65	780.00
1 chief of watch, 12 months, at $65	780.00
1 chief of watch, 12 months, at $65	780.00
1 watchman, 12 months, at $50	600.00

1 watchman, 11 months 26 days, at $40	$473.55
1 watchman, 4 months 13 days, at $45	200.89
1 watchman, 12 months, at $50	600.00
1 watchman, 12 months, at $50	600.00
1 watchman, 12 months, at $50	600.00
1 watchman, 12 months, at $65	780.00
1 watchman, 11 months and 27 days, at $45	535.50
1 watchman, 12 months, at $45	540.00
1 watchman, 10 months 31 days, at $45	496.21
1 watchman, 12 months, at $50	600.00
1 watchman, 12 months, at $50	600.00
1 watchman, 12 months, at $50	600.00
1 watchman, 8 days, at $45, $12; 4 months, at $45, $180	192.00
1 watchman, 12 months, at $45	540.00
1 watchman, 12 months, at $45	540.00
1 watchman, 11 months 28 days, at $45	535.65
1 watchman, 12 months, at $45	540.00
1 watchman, 11 months 27 days, at $45	535.50
1 watchman, 8 months 46 days, at $50	476.96
1 watchman, 10 months 27 days, at $50	545.00
1 watchman, 1 month, at $50; 11 months, at $30	380.00
1 watchman, 7 months 27 days, at $45	355.50
1 watchman, 12 months, at $50	600.00
1 watchman, 12 months, at $50	600.00
1 watchman, 12 months, at $45	540.00
1 acting watchman, 12 months, at $45	540.00
1 skilled laborer, 31 days, at $60	61.74
1 skilled laborer, 12 months, at $50	600.00
1 skilled laborer, 11 months 28½ days, at $55	657.25
1 skilled laborer, 12 months, at $50	600.00
1 workman, 12 months, at $50	600.00
1 workman, 288 days, at $1.50	432.00
1 workman, 316 days, at $1.50	474.00
1 workman, 334 days, at $1.50	501.00
1 workman, 298 days, at $1.50	447.00
1 laborer, 104½ days, at $1.50	156.75
1 laborer, 248 days, at $1.50	372.00
1 laborer, 27 days, at $1.50	40.50
1 laborer, 313 days, at $1.50	469.50
1 laborer, 7 days, at $1.50	10.50
1 laborer, 78 days, at $1.50	117.00
1 laborer, 6 months, at $30, $180; 1 month, at $31.50; 2 months, at $34.50, $69; 2 months, at $33, $66; 1 month, at $45	391.50
1 laborer, 12 months, at $40	480.00
1 laborer, 129 days, at $1.50	193.50
1 laborer, 87 days, at $1.50	130.50
1 laborer, 313 days, at $1.50	469.50
1 laborer, 155 days, at $1	155.00
1 laborer, 26 days, at $1	26.00
1 laborer, 218 days, at $1.50	327.00
1 laborer, 208 days, at $1.50	312.00
1 laborer, 1 month 29 days, at $30	58.06
1 laborer, 208 days, at $1.50	312.00
1 laborer, 78 days, at $1.50	117.00
1 laborer, 162½ days, at $1.50	243.75
1 laborer, 7 days, at $1.50	10.50

1 laborer, 155 days, at $1.50	$232.50
1 laborer, 313 days, at $1.50	469.50
1 laborer, 170¼ days, at $1.50	255.38
1 laborer, 1 month, at $40	40.00
1 laborer, 1 month, at $40	40.00
1 laborer, 313 days, at $1.50	469.50
1 laborer, 7 months, at $30, $210; 1 month, at $31.50	241.50
1 laborer, 1 month, at $40; 286 days, at $1	326.00
1 laborer, 53 days, at $1.50	79.50
1 laborer, 3 months 24½ days, at $40	154.58
1 laborer, 26 days, at $1.50	39.00
1 laborer, 65 days, at $1.50	97.50
1 laborer, 3 months, at $40	120.00
1 laborer, 139 days, at $1.50	208.50
1 laborer, 77 days, at $1	77.00
1 laborer, 8 days, at $1	8.00
1 laborer, 65 days, at $1.50	97.50
1 laborer, 1 month, at $40; 286 days, at $1	326.00
1 laborer, 32 days, at $1.50	48.00
1 laborer, 26 days, at $1	26.00
1 laborer, 26 days, at $1.50	39.00
1 laborer, 7 days, at $1.50, $10.50; 26 days, at $39	49.50
1 laborer, 21 days, at $1.50	31.50
1 laborer, 27 days, at $1.50	40.50
1 laborer, 211 days, at $1.50	316.50
1 laborer, 1 month, at $40; 286 days, at $1	326.00
1 laborer, 31 days, at $1.50	46.50
1 laborer, 27 days, at $1.50	40.50
1 laborer, 12 months, at $40	480.00
1 laborer, 162½ days, at $1.50	243.75
1 laborer, 314 days, at $1.50	471.00
1 laborer, 93 days, at $1.50	139.50
1 laborer, 127 days, at $1.50	190.50
1 laborer, 313 days, at $1.50	469.50
1 laborer, 13½ days, at $1.50	20.25
1 laborer, 165 days, at $1.50	247.50
1 laborer, 66 days, at $1.50	99.00
1 laborer, 163 days, at $1.50	244.50
1 laborer, 9 months 4 days, at $40	365.33
1 laborer, 161 days, at $1.50	241.50
1 messenger, 6 months, at $25; 6 months, at $40	390.00
1 messenger, 12 months, at $25	300.00
1 messenger, 1 month 18 days, at $25	39.52
1 messenger, 12 months, at $25	300.00
1 messenger, 19 days, at $20; 11 days, at $20	19.59
1 messenger, 10 months 10 days, at $25	258.06
1 messenger, 12 months, at $50	600.00
1 messenger and copyist, 6 months 53 days, at $30; 4 months, at $40	391.29
1 attendant, 14 days, at $1	14.00
1 attendant, 12 months, at $40	480.00
1 cleaner, 281 days, at $1	281.00
1 cleaner, 9 months 4 days, at $30	274.00
1 cleaner, 1 month, at $30	30.00
1 cleaner, 1 month, at $30	30.00
1 cleaner, 1 month, at $30	30.00

1 cleaner, 1 month, at $30		$30.00	
1 cleaner, 12 months, at $30		360.00	
1 cleaner, 1 month, at $30		30.00	
1 cleaner, 5 days, at $30		4.84	
1 cleaner, 1 month, at $30		30.00	
1 cleaner, 1 month, at $30		30.00	
1 cleaner, 8 months 19 days, at $30		258.39	
			$38,871.29
Total salaries			139,614.18
Deduct dissallowance on voucher No. 396			25.50
Total			139,588.68

PRESERVATION OF COLLECTIONS, 1897.

Balance as per report July 1, 1897			$4,201.93
Salaries	$6.45		
Special services	1,016.90		
		$1,023.35	
Supplies	509.80		
Stationery	354.59		
Specimens	922.87		
Books	371.58		
Travel	346.78		
Freight	292.97		
		2,798.59	
Total expenditures			3,821.94
Balance July 1, 1898, to meet liabilities			379.99

Analysis of expenditures for salaries.

Scientific staff, 1 aid, 2 days, at $100 .... $6.45

Total statement of receipts and expenditures of the appropriation for preservation of collections, 1897.

RECEIPTS.

Appropriation June 11, 1896 .... $153,225.00

EXPENDITURES.

Salaries or compensation	$134,364.19	
Special services	5,671.23	
Total services	140,035.42	
Miscellaneous:		
Supplies	3,343.64	
Stationery	1,373.17	
Specimens	4,102.44	
Books	1,682.70	
Travel	785.77	
Freight	1,521.87	
Total expenditures		$152,845.01
Balance July 1, 1898		379.99

PRESERVATION OF COLLECTIONS, 1896.

Balance as per last report, July 1, 1897 .... $1.32

Balance carried, under the provisions of Revised Statutes, section 3090, by the Treasury Department to the credit of the surplus fund, June 30, 1898.

FURNITURE AND FIXTURES, 1898.

RECEIPTS.

Appropriation by Congress for the fiscal year ending June 30, 1898, "for cases, furniture, fixtures, and appliances required for the exhibition and safe-keeping of the collections of the National Museum, including $15,000 for furnishing new galleries, and including salaries or compensation of all necessary employees" (sundry civil act, June 4, 1897) .. $30,000.00

EXPENDITURES.

(July 1, 1897, to June 30, 1898.)

Salaries or compensation	$8,855.71	
Special or contract services	392.61	
		$9,248.32
Miscellaneous:		
Exhibition cases	115.00	
Storage cases	162.50	
Drawers, trays, boxes	521.85	
Frames, stands, and miscellaneous woodwork	113.40	
Glass	625.66	
Hardware and interior fittings for cases	710.33	
Tools	67.36	
Cloth, cotton, etc	74.49	
Glass jars, bottles, etc	441.34	
Lumber	1,006.91	
Paints, oils, glue, brushes	546.78	
Office and hall furniture and furnishings	581.35	
Plumbing	12.92	
Leather and rubber	29.34	
Iron brackets	195.69	
Travel	34.30	
Apparatus	21.96	
Brick, plaster, tiles	75.53	
		5,336.71
Furnishing new galleries:		
Salaries or compensation	4,800.75	
Special or contract services	9.50	
		4,810.25
Miscellaneous:		
Exhibition cases	5,507.90	
Storage cases	415.00	
Drawers, trays, boxes	207.36	
Designs and drawings for cases	293.00	
Frames, stands, and miscellaneous woodwork	387.62	
Glass	859.34	
Hardware	442.90	
Cloth, cotton, etc	15.10	
Lumber	520.04	
Office and hall furniture and furnishings	8.00	

Iron brackets	$36.00		
Apparatus	200.00		
Plaster	2.00		
		$8,894.26	
Total expenditures to June 30, 1898			$28,289.54
Balance July 1, 1898, to meet outstanding liabilities			1,710.46

Analysis of expenditures for salaries.

1 supervisor of construction, 1 month 35 days, at $115	$253.00
1 copyist, 6 months, at $40	240.00
1 cabinetmaker, 286 days, at $2.25; 27 days, at $3	724.50
1 case finisher, 55½ days, at $2.25	118.25
1 carpenter, 19 days, at $3	57.00
1 carpenter, 77 days, at $3; 6 days, at $3	249.00
1 carpenter, 72 days, at $3	216.00
1 carpenter, 25 days, at $3	75.00
1 carpenter, 21¾ days, at $3	65.25
1 carpenter, 18½ days, at $3	55.50
1 carpenter, 36 days, at $3	108.00
1 carpenter, 215 days, at $3	645.00
1 carpenter, 6 days, at $3; 80 days, at $3	258.00
1 carpenter, 16 days, at $3	48.00
1 carpenter, 64 days, at $3; 3 days, at $3	201.00
1 carpenter, 25 days, at $3	75.00
1 carpenter, 242 days, at $3	726.00
1 carpenter, 41 days, at $3	123.00
1 carpenter, 211¼ days, at $3	633.75
1 carpenter, 3 days, at $3; 6 days, at $3; 172 days, at $3	543.00
1 carpenter, 314 days, at $3	942.00
1 carpenter, 20 days, at $3	60.00
1 carpenter, 48 days, at $3	144.00
1 carpenter, 3½ days, at $3	10.50
1 carpenter, 22 days, at $3	66.00
1 carpenter, 24 days, at $3	72.00
1 carpenter, 38 days, at $3	114.00
1 carpenter, 236 days, at $3	708.00
1 carpenter, 151 days, at $3; 6 days, at $3	471.00
1 carpenter, 128 days, at $3; 4 days, at $3	396.00
1 carpenter, 15 days, at $3	45.00
1 carpenter, 157¾ days, at $3	473.25
1 skilled laborer, 308¾ days, at $2	617.50
1 skilled laborer, 77 days, at $2	154.00
1 skilled laborer, 76½ days, at $2	153.00
1 skilled laborer, 26½ days, at $2	53.00
1 skilled laborer, 23 days, at $2	46.00
1 skilled laborer, 79½ days, at $2	159.00
1 skilled laborer, 12 days, at $2	24.00
1 skilled laborer, 12 months, at $60	720.00
1 skilled laborer, 79½ days, at $2	159.00
1 skilled laborer, 4 months 19 days, at $50	231.67
1 skilled laborer, 22 days, at $2	44.00
1 skilled laborer, 25½ days, at $2	51.00
1 skilled laborer, 173½ days, at $2	347.00
1 skilled laborer, 79½ days, at $2	159.00

1 skilled laborer, 255 days, at $2			$510.00
1 skilled laborer, 26½ days, at $2			53.00
1 painter, 9 months 24 days, at $65			636.79
1 workman, 322 days, at $1.50			483.00
1 laborer, 53 days, at $1.50			79.50
1 laborer, 1 month, at $30			30.00
1 laborer, 1 month, at $30			30.00
Total salaries			13,656.46

FURNITURE AND FIXTURES, 1897.

RECEIPTS.

Balance as per report July 1, 1897			$1,801.07

EXPENDITURES.

Special services	$4.75		
Total salaries		$4.75	
Miscellaneous:			
Drawers	$267.00		
Frames	12.50		
Glass	509.10		
Hardware	188.82		
Tools	55.40		
Cloth	169.06		
Glass jars	34.85		
Lumber	368.85		
Paints and oils	42.75		
Office furniture	30.75		
Rubber	33.76		
Plumbing	75.18		
		1,788.02	
Total expenditures			1,792.77
Balance July 1, 1898			8.30

FURNITURE AND FIXTURES, 1897.

Total statement of appropriation for 1897.

RECEIPTS.

Appropriation by Congress			$15,000.00

EXPENDITURES.

Salaries or compensation	$8,062.43		
Special services	252.40		
Total salaries		$8,314.83	
Miscellaneous:			
Cases	150.50		
Drawers	553.93		
Frames	49.30		
Glass	1,122.84		
Hardware	1,143.81		
Tools	138.94		
Cloth	255.50		

Miscellaneous—Continued.			
Glass jars	$660.37		
Lumber	1,206.44		
Paints and oils	412.48		
Office furniture	637.37		
Rubber	68.40		
Plumbing	126.18		
Iron brackets	146.81		
Brick, stone, etc	4.00		
		$6,676.87	
Total expenditures			$14,991.70
Balance July 1, 1898			8.30

FURNITURE AND FIXTURES, 1896.

Balance July 1, 1897, as per last annual report $0.20

Balance carried, under the provisions of Revised Statutes, section 3090, by the Treasury Department to the credit of the surplus fund, June 30, 1898.

HEATING, LIGHTING, ETC., 1898.

RECEIPTS.

Appropriation by Congress for the fiscal year ending June 30, 1898, "for expense of heating, lighting, electrical, telegraphic, and telephonic service for the National Museum" (sundry civil act, June 4, 1897)..... $14,000.00

EXPENDITURES.

Salaries	$6,542.04		
Special services	165.17		
Total services		$6,707.21	
Miscellaneous:			
Coal and wood	3,318.45		
Gas	1,180.10		
Telephones	611.50		
Rental of call boxes	100.00		
Electrical supplies	413.23		
Telegrams	19.51		
Heating supplies	833.13		
Total miscellaneous		6,475.92	
Total expenditures			13,183.13
Balance July 1, 1898 (to meet outstanding liabilities)			816.87

Analysis of expenditures for salaries.

1 engineer, 12 months, at $115	$1,380.00
1 stenographer and typewriter, 14 days, at $75	33.87
1 telephone operator, 6 months, at $45; 5 months, 27 days, at $50	565.00
1 machinist, 10 days, at $3	30.00
1 pipe fitter, 6 days, at $3	18.00
1 skilled laborer, 12 months, at $75	900.00
1 skilled laborer, 12 months, at $60	720.00
1 skilled laborer, 1 day, at $2	2.00
1 skilled laborer, 1 day, at $2	2.00
1 skilled laborer, 12 months, at $55	660.00

1 fireman, 12 months, at $50	$600.00
1 fireman, 7 months 28 days, at $50	396.67
1 fireman, 12 months, at $50	600.00
1 acting fireman, 1 month, at $45	45.00
1 laborer, 313 days, at $1.50	469.50
1 laborer, 27 days, at $1.50	40.50
1 laborer, 26 days, at $1.50	39.00
1 laborer, 27 days, at $1.50	40.50
Total salaries	6,542.04

HEATING, LIGHTING, ETC., 1897.

RECEIPTS.

Balance as per report July 1, 1897		$742.11
General expenses:		
Gas	$70.30	
Telephones	189.87	
Electrical supplies	79.37	
Rental of call-boxes	10.00	
Heating supplies	383.94	
Telegrams	5.79	
Total expenditure		739.27
Balance July 1, 1898		2.84

Total statement of appropriation for heating and lighting Museum, 1897.

RECEIPTS.

Appropriation by Congress, June 11, 1896			$13,000.00

EXPENDITURES.

Salaries or compensation	$6,269.05		
Special services	21.75		
Total services		$6,290.80	
General expenses:			
Coal and wood	3,676.82		
Gas	1,037.20		
Telephones	689.41		
Electrical supplies	505.98		
Rental of call-boxes	120.00		
Heating supplies	665.81		
Telegrams	11.14		
Total		6,706.36	
Total expenditure			12,997.16
Balance July 1, 1898			2.84

HEATING, LIGHTING, ETC., 1896.

Balance July 1, 1897, as per last annual report	$0.42

Balance carried, under the provisions of Revised Statutes, section 3090, by the Treasury Department to the credit of the surplus fund, June 30, 1898.

NATIONAL MUSEUM—POSTAGE, 1898.

RECEIPTS.

Appropriation by Congress for the fiscal year ending June 30, 1898, "for postage stamps and foreign postal cards for the National Museum" (sundry civil act, June 4, 1897) $500.00

EXPENDITURES.

For postage stamps and cards 500.00

NATIONAL MUSEUM—PRINTING AND BINDING, 1898.

RECEIPTS.

Appropriation by Congress for the Smithsonian Institution "for printing labels and blanks for the 'bulletins' and annual volumes of the 'proceedings' of the National Museum, the editions of which shall be not less than 3,000 copies, and binding scientific books and pamphlets presented to and acquired by the National Museum library" (sundry civil act, June 4, 1897) $12,000.00

EXPENDITURES.

Bulletins, National Museum	$3,861.98	
Proceedings, National Museum	6,913.18	
Labels	244.81	
Letter-heads, pads, and envelopes	44.60	
Blanks	50.44	
Binding	527.00	
Congressional Record	24.00	
Record books	311.20	
Total expenditures		11,977.21
Balance July 1, 1898		22.79

NATIONAL MUSEUM—RENT OF WORKSHOPS, 1898.

RECEIPTS.

Appropriation by Congress for the fiscal year ending June 30, 1898, "for rent of workshops for the National Museum" $2,000.00

EXPENDITURES.

For rent of workshops (431 Ninth street SW)	1,999.92
Balance July 1, 1898	.08

NATIONAL MUSEUM—RENT OF WORKSHOPS, 1897.

Balance July 1, 1897, as per last annual report	$0.08
Balance July 1, 1898	.08

NATIONAL MUSEUM—BUILDING REPAIRS, 1898.

RECEIPTS.

Appropriation by Congress for the fiscal year ending June 30, 1898, "for repairs to buildings, shops, and sheds, National Museum, including all necessary labor and material" (sundry civil act, June 4, 1897) $4,000.00

EXPENDITURES.

Salaries or compensation:			
Carpenters, 128 days, at $3	$384.00		
Plasterers, 38 days, at $2.48	94.24		
Bricklayer, 2 days, at $4	8.00		
Skilled laborers, 125 days, at $2	250.00		
Laborers, 857 days, at $1.50	1,285.50		
Laborers, 103 days, at $1	103.00		
Special services	232.80		
		$2,357.54	
Miscellaneous:			
Granolithic pavement	803.15		
Arches and terrazzo pavement	265.60		
Iron columns	260.86		
Hardware	74.70		
Glass	6.25		
Lumber	13.50		
Brick, sand, marble, cement, etc	176.42		
Frames, etc	10.00		
		1,610.48	
Total expenditures			$3,968.02
Balance July 1, 1898			31.98

NATIONAL MUSEUM—BUILDING REPAIRS, 1897.

RECEIPTS.

Balance as per report, July 1, 1897	$115.25

EXPENDITURES.

Miscellaneous:		
Flue	$25.00	
Lime, sand, gravel, etc	31.55	
White lead	27.23	
Hardware	10.65	
Rope	3.34	
Iron grill	8.90	
Door	8.00	
Total expenditure		114.67
Balance July 1, 1898		.58

Total statement of appropriation for Museum building repairs, 1897

RECEIPTS.

Appropriation by Congress June 11, 1896	$4,000.00

EXPENDITURES.

Salaries or compensation	$2,792.37	
Special services	489.00	
Total services		$3,281.37
Miscellaneous:		
Lumber	78.89	
Frames and woodwork	486.30	
Glass	30.29	
Hardware	15.85	
Brick	2.70	
Flue	25.00	

Miscellaneous—Continued.

Lime, sand, gravel	$31.55		
White lead	27.23		
Rope	3.34		
Iron grill	8.90		
Door	8.00		
		$718.05	
Total expenditure			$3,999.42
Balance July 1, 1898			.58

NATIONAL MUSEUM—BUILDING REPAIRS, 1896.

Balance July 1, 1897, as per last annual report $1.38

Balance carried, under the provisions of Revised Statutes, section 3090, by the Treasury Department to the credit of the surplus fund, June 30, 1898.

NATIONAL MUSEUM—GALLERIES, 1898.

RECEIPTS.

Appropriation by Congress for the fiscal year ending June 30, 1898, "for the continuation of the construction of galleries in the National Museum building, said galleries to be constructed under the direction of the superintendent of the Congressional Library, in accordance with the approval of the Secretary of the Smithsonian Institution (sundry civil act June 4, 1897) $8.000.00

EXPENDITURES.

Salaries:			
1 inspector, 90½ days, at $3	$271.50		
1 laborer, 6 days, at $1.50	9.00		
Special services	471.03		
		$751.53	
Miscellaneous:			
Drawings and blue prints	58.65		
Arches and pavements	4,979.50		
Iron columns and steel beams	1,410.00		
Iron columns and steel beams, erection	75.00		
Lumber	7.10		
Advertising	21.75		
Hardware	6.60		
Brick, lime, sand, etc	138.00		
		6,696.60	
Total			7,448.13
Balance July 1, 1898, to meet outstanding liabilities			551.87

GALLERIES, 1897.

RECEIPTS.

Balance as per report July 1, 1897 .... $4,024.35

EXPENDITURES.

Miscellaneous:		
Drawings and blue prints	$12.00	
Advertising	17.50	
Steel and iron stairways	1,780.00	
Cement arches and pavement	2,214.80	
Total expenditures		4,024.30
Balance July 1, 1898		.05

Total statement of appropriation for Museum galleries, 1897.

RECEIPTS.

Appropriation by Congress, June 11, 1896			$8,000.00

EXPENDITURES.

Salaries	$246.25		
Special services	272.78		
Total services		$519.03	
Miscellaneous:			
Steel beams and iron columns	$3,200.00		
Drawings and blue prints	153.95		
Brick, sand, cement, and gravel	54.05		
Advertising proposals	78.12		
Steel and iron stairways	1,780.00		
Cement arches	1,267.30		
Terrazzo floors	947.50		
		7,480.92	
Total expenditures			$7,999.95
Balance July 1, 1898			.05

NATIONAL MUSEUM—BUILDING SHEDS, ETC., 1898.

RECEIPTS.

Appropriation by Congress for the fiscal year ending June 30, 1898, "for removal of the sheds from their present location south of and adjacent to the Smithsonian building and rebuilding them, including all necessary labor and material" (sundry civil act, June 4, 1897)			$2,500.00

EXPENDITURES.

Inspector of work, 42½ days, at $3	$127.50		
Carpenters, 249 days, at $3	747.00		
Pipe-fitters, 20 days, at $3	60 00		
Tinner, 12 days, $3	36.00		
Skilled laborers, 23 days, at $2.50	81.88		
Skilled laborers, 6 days, at $2	12.00		
Laborers, 260½ days, at $1.50	390.38		
		$1,454.76	
Special services		131.20	
		1,585.96	
Miscellaneous:			
Lumber	$342.27		
Hardware	178.32		
Brick, etc	222.85		
Frames	141.70		
		885.14	
Total expenditures			$2,471.10
Balance July 1, 1898			28.90

ASTROPHYSICAL OBSERVATORY, SMITHSONIAN INSTITUTION, 1898.

RECEIPTS.

Appropriation by Congress "for maintenance of astrophysical observatory under the direction of the Smithsonian Institution, including salaries of assistants, apparatus, and miscellaneous expenses" (sundry civil act, June 4, 1897)			$10,000.00

DISBURSEMENTS.

(From July 1, 1897, to June 30, 1898.)

Salaries or compensation:			
1 aid, 6 months, at $133.34, and 6 months, at $166.67		$1,800.09	
1 junior assistant, 12 months, at $100		1,200.00	
1 junior assistant, 1 month, at $100		100.00	
1 clerk, 1 month, at $100		100.00	
1 junior assistant, 3 days, at $75 per month		7.25	
1 instrument maker, 5½ months and 7½ days, at $75, and 2 months, at $80		591.25	
1 stenographer, 12 months, at $60		720.00	
1 copyist, 60 days, at $25 per month		49.17	
1 fireman, 3 months and 46 days, at $45		204.11	
1 carpenter, 44½ days, at $3		133.50	
1 carpenter, 3 days, at $3		9.00	
1 carpenter, 46 days, at $3		138.00	
1 carpenter, 4 days, at $3		12.00	
1 painter, 9 days, at $2, and 3 days, at $3		27.00	
1 painter, 9 days, at $2		18.00	
1 skilled laborer, 1½ days, at $55 per month		2.75	
1 skilled laborer, 2 days, at $2		4.00	
Total salaries or compensation		5,116.12	
General expenses:			
Apparatus	$1,284.49		
Books	179.81		
Freight	37.32		
Fuel	114.96		
Illustrations	56.25		
Lumber	71.09		
Stationery	3.73		
Supplies	428.30		
Miscellaneous	6.15		
		2,182.10	
Total disbursements			$7,298.22
Balance July 1, 1898, to meet liabilities			2,701.78

ASTROPHYSICAL OBSERVATORY, 1897.

Balance July 1, 1897, as per last report		$2,426.44

Disbursements July 1, 1897, to June 30, 1898.

General expenses:		
Apparatus	$2,250.08	
Books	35.68	
Freight	7.15	
Lumber	52.40	
Supplies, etc	57.71	
		$2,403.02
Balance July 1, 1898, to meet liabilities		23.42

ASTROPHYSICAL OBSERVATORY, 1896.

Balance July 1, 1897, as per last report	$56.50

Disbursements July 1, 1897, to June 30, 1898.

General expenses:

Books	$48.96
Balance	7.54

Balance carried, under the provisions of Revised Statutes, section 3090, by the Treasury Department to the credit of the surplus fund, June 30, 1898.

NATIONAL ZOOLOGICAL PARK, 1898.

Appropriation by Congress "for continuing the construction of roads, walks, bridges, water supply, sewerage, and drainage; and for grading, planting, and otherwise improving the grounds; erecting and repairing buildings and inclosures; care, subsistence, purchase, and transportation of animals, including salaries or compensation of all necessary employees and general incidental expenses not otherwise provided for, fifty-five thousand dollars; one-half of which sum shall be paid from the revenues of the District of Columbia and the other half from the Treasury of the United States; and of the sum hereby appropriated five thousand dollars shall be used for continuing the entrance into Zoological Park from Woodley lane and opening driveway into Zoological Park, from said entrance along the bank of Rock Creek" (sundry civil act, June 4, 1897) $55,000.00

Disbursements July 1, 1897, to June 30, 1898.

Salaries or compensation:

1 superintendent, 12 months, at $225	$2,700.00
1 property clerk, 12 months, at $125	1,500.00
1 clerk, 12 months, at $75	900.00
1 stenographer, 12 months, at $62.50	750.00
1 copyist, 12 months, at $50	600.00
1 head keeper, 12 months, at $100	1,200.00
1 keeper, 12 months, at $60	720.00
1 keeper, 12 months, at $60	720.00
1 keeper, 12 months, at $60	720.00
1 keeper, 12 months, at $60	720.00
1 keeper, 12 months, at $60	720.00
1 keeper of aquarium, 2 months 13 days, at $75	182.50
1 watchman, 9 months 22 days, at $60	584.00
1 watchman, 10 months 19½ days, at $50	531.45
1 watchman, 12 months, at $50	600.00
1 watchman, 12 months, at $50	600.00
1 landscape gardener, 12 months, at $75	900.00
1 assistant foreman, 12 months, at $60	720.00
1 blacksmith, 12 months, at $75	900.00
1 assistant blacksmith, 12 months, at $60	720.00
1 carpenter, 10 months 15 days, at $75	787.50
1 workman, 12 months, at $60	720.00
1 workman, 12 months, at $50	600.00
1 workman, 11 months 6 days, at $50	560.00
1 laborer, 12 months, at $50	600.00
1 laborer, 12 months, at $50	600.00
1 laborer, 10 months 8 days, at $50	512.90
1 laborer, 12 months, at $50	600.00
1 laborer, 12 months, at $45	540.00
1 laborer, 12 months, at $20	240.00
Total salaries or compensation	22,748.35

Miscellaneous:

Buildings	$1,461.78
Building materials	865.68
Fencing and cage materials	522.98
Food	4,741.58
Freight and transportation	933.70
Fuel	531.56
Lumber	2,010.50
Machinery, tools, etc	447.00
Miscellaneous	723.45
Paints, oils, glass, etc	199.33
Postage, telegraph, and telephones	186.42
Purchase of animals	1,643.00
Road material, grading, and bridges	2,819.98
Surveying, plans, etc	300.00
Stationery, books, etc	177.37
Traveling expenses	274.29
Trees, plants, etc	773.88
Water supply, sewerage, etc	260.87
Total miscellaneous	18,873.37

Wages of mechanics and laborers and hire of teams in constructing buildings and inclosures, laying water pipes, building roads, gutters, and walks, planting trees, and otherwise improving the grounds:

1 laborer, 233½ days, at $2	467.00
1 laborer, 365 days, at $2	730.00
1 laborer, 321¾ days, at $1.50	482.64
1 laborer, 283½ days, at $1.50	425.24
1 laborer, 50½ days, at $1.50	75.75
1 laborer, 48½ days, at $1.50	72.76
1 laborer, 254¾ days, at $1.50	382.13
1 laborer, 19 days, at $1.50	28.50
1 laborer, 79 days, at $1.50	118.50
1 laborer, 96½ days, at $1.50	144.76
1 laborer, 171½ days, at $1.50	257.25
1 laborer, 187½ days, at $1.50	281.25
1 laborer, 76 days, at $1.50	114.00
1 laborer, 102 days, at $1.50	153.01
1 laborer, 8 days, at $1.50	12.00
1 laborer, 30 days, at $1.50	45.00
1 laborer, 48½ days, at $1.50	72.75
1 laborer, 244¼ days, at $1.50	366.38
1 laborer, 51 days, at $1.50	76.50
1 laborer, 90¼ days, at $1.50	198.36
1 laborer, 256 days, at $1.50	384.00
1 laborer, 9½ days, at $1.50	14.25
1 laborer, 172¾ days, at $1.50	259.13
1 laborer, 92½ days, at $1.50	138.74
1 laborer, 277½ days, at $1.50	416.27
1 laborer, 59 days, at $1.50	88.50
1 laborer, 327¼ days, at $1.50	490.87
1 laborer, 65¼ days, at $1.50	97.87
1 laborer, 77½ days, at $1.50	116.25
1 laborer { 191½ days, at $1.50	287.25
{ 15 days, at $1.25	18.75

Wages of mechanics and laborers, etc.—Continued.

1 laborer	12 days, at $1.50	$18.00
	54 days, at $1.25	67.54
1 laborer	94¾ days, at $1.50	142.13
	13 days, at $2	26.00
1 laborer	61¾ days, at $1.50	92.63
	35½ days, at $1.25	44.37
1 laborer	41 days, at $1.50	61.51
	152¼ days, at $1.75	266.43
1 laborer, 5¼ days, at $1.25		6.56
1 laborer, 50¼ days, at $1.25		62.80
1 laborer, 7½ days, at $1.25		9.37
1 laborer, 22¼ days, at $1.25		27.81
1 laborer, 12½ days, at $1.25		15.62
1 laborer, 45¾ days, at $1.25		57.19
1 laborer, 43¾ days, at $1.25		54.68
1 laborer, 7½ days, at $1.25		9.37
1 laborer, 12 days, at $1.25		15.00
1 laborer, 7½ days, at $1.25		9.37
1 laborer, 9½ days, at $1.25		11.88
1 laborer, 1¾ days, at $1.25		2.19
1 laborer, 25¼ days, at $1.25		31.56
1 laborer, 12½ days, at $1.25		15.62
1 laborer, 18½ days, at $1.25		23.13
1 laborer, 36¾ days, at $1.25		45.93
1 laborer, 13¾ days, at $1.25		17.18
1 laborer, 49¼ days, at $1.25		61.56
1 laborer, 35¼ days, at $1.25		44.06
1 laborer, 41½ days, at $1.25		51.88
1 laborer, 59½ days, at $1.25		74.37
1 laborer, 14½ days, at $1.25		18.12
1 laborer, 53 days, at $1.25		66.25
1 laborer, 6½ days, at $1.25		8.12
1 laborer, 20¾ days, at $1.25		25.93
1 laborer, 12½ days, at $1.25		15.62
1 laborer, 125¼ days, at $1.25		156.55
1 laborer, 93 days, at $1.25		116.25
1 laborer, 10½ days, at $1.25		13.12
1 laborer, 11¼ days, at $1.25		14.06
1 laborer, 7½ days, at $1.25		9.37
1 laborer, 10¾ days, at $1.25		13.44
1 laborer, 5¾ days, at $1.25		7.19
1 laborer, 1½ days, at $1.25		1.88
1	laborer, 11¼ days, at $1.25	14.06
	stonebreaker, 5 yards, at 60 cents	3.00
1	laborer, 13¼ days, at $1.25	16.56
	stonebreaker, 6 yards, at 50 cents	3.00
	stonebreaker, 95⅙ yards, at 60 cents	57.10
1 laborer, 169¾ days, at $1		169.75
1 laborer, 3 days, at $1		3.00
1 laborer, 23¾ days, at 75 cents		17.81
1 workman, 365 days, at $1.75		638.75
1 bricklayer, 1 day, at $4		4.00
1 bricklayer, 2 days, at $4		8.00
1 bricklayer, 5¼ days, at $4		21.00

Wages of mechanics and laborers, etc.—Continued.

1 carpenter, 34 days, at $3	$102.00	
1 { carpenter, 30 days, at $2.50	75.00	
{ laborer, 13 days, at $1.50	19.50	
1 water boy, 61 days, at 50 cents	30.50	
1 water boy { 129½ days, at 50 cents	64.75	
{ 187 days, at 75 cents	140.25	
1 water boy, 1 day, at 50 cents	.50	
1 water boy, 12¼ days, at 50 cents	6.12	
1 water boy, 15 days, at 75 cents	11.25	
1 stonebreaker, 7 yards, at 60 cents	4.20	
1 stonebreaker, 8 yards, at 60 cents	4.80	
1 stonebreaker, 7½ yards, at 60 cents	4.50	
1 stonebreaker, 19 yards, at 60 cents	11.40	
1 stonebreaker, 19 yards, at 60 cents	11.40	
1 stonebreaker, 17 yards, at 60 cents	10.20	
1 stonebreaker { 2½ yards, at 60 cents	1.50	
{ 4⅓ yards, at 50 cents	2.17	
1 weeder, 76 days, at 50 cents	38.00	
1 wagon and team, 21 days, at $3.50	73.50	
1 { wagon and team, 54¼ days, at $3.50	189.87	
{ wagon and team, 37½ days, at $3	112.50	
{ horse and cart, 23½ days, at $1.75	41.12	
{ horse and cart, 68¾ days, at $1.50	103.12	
1 wagon and team, 10½ days, at $3.50	36.75	
1 wagon and team, ½ day, at $3.50	1.75	
1 wagon and team, 13½ days, at $3.50	47.25	
1 wagon and team, 15½ days, at $3.50	54.25	
1 wagon and team, 17¾ days, at $3	53.25	
1 wagon and team, 9 days, at $3	27.00	
1 horse and cart, 1 day, at $1.75	1.75	
1 horse and cart, 21 days, at $1.75	36.75	
1 horse and cart, 6½ days, at $1.75	11.38	
1 horse and cart { 18½ days, at $1.75	32.38	
{ 2 days, at $1.50	3.00	
1 horse and cart { 12 days, at $1.75	21.00	
{ 2½ days, at $1.50	3.75	
1 horse and cart, 7 days, at $1.75	12.25	
1 horse and cart, 2 days, at $1.75	3.50	
1 horse and cart { 115¼ days, at $1.75	201.69	
{ 37¾ days, at $1.50	56.62	
1 horse and cart, 11¾ days, at $1.75	20.56	
1 horse and cart, 43¾ days, at $1.75	76.56	
1 horse and cart, 17¾ days, at $1.75	31.06	
1 horse and cart, 2½ days, at $1.75	4.37	
1 horse and cart, 5½ days, at $1.75	9.62	
1 horse and cart, 2½ days, at $1.75	4.37	
1 horse and cart, 2 days, at $1.75	3.50	
1 horse, 92¼ days, at 50 cents	46.13	
1 draftsman, 82 days, at $2	164.00	
Total wages, mechanics, etc	11,625.94	
Total disbursements		53,247.66
Balance July 1, 1898, to meet liabilities		1,752.34

NATIONAL ZOOLOGICAL PARK, 1897.

Balance July 1, 1897, as per last report		$1,567.03

DISBURSEMENTS.

General expenses:		
Books	$27.30	
Drawings, plans, etc	726.50	
Food	427.11	
Freight	145.38	
Miscellaneous	16.45	
Lumber	45.61	
Supplies	65.81	
Stationery	6.00	
Telephones, messengers, etc	66.90	
Traveling expenses	27.45	
		1,554.51
Balance July 1, 1898		12.52

NATIONAL ZOOLOGICAL PARK, 1896.

Balance July 1, 1897, as per last report	$23.23

DISBURSEMENTS.

General expenses:	
Supplies	23.10
Balance	.13

Balance carried, under the provisions of Revised Statutes, section 3090, by the Treasury Department to the credit of the surplus fund, June 30, 1898.

RECAPITULATION.

The total amount of funds administered by the institution during the year ending June 30, 1898, appears from the foregoing statements and the account books to have been as follows:

SMITHSONIAN INSTITUTION.

From balance of last year, July 1, 1897		$61,532.50	
(Including cash from executors of Dr. J. H. Kidder)	$5,000.00		
(Including cash from gift of Alex. Graham Bell)	5,000.00		
	10,000.00		
From interest on Smithsonian fund for the year		54,720.00	
From interest on West Shore bonds		1,680.00	
From sales of publications		458.08	
From repayments of freight, etc		10,320.14	
			128,710.72

APPROPRIATIONS COMMITTED BY CONGRESS TO THE CARE OF THE INSTITUTION.

International exchanges—Smithsonian Institution:		
From balance of 1895–96	$0.03	
From balance of 1896–97	179.63	
From appropriation for 1897–98	19,000.00	
		$19,179.66

North American Ethnology—Smithsonian Institution:		
From balance of 1895–96	$56.52	
From balance of 1896–97	218.04	
From appropriation for 1897–98	45,000.00	
		$45,274.56
Preservation of collections—National Museum:		
From balance of 1895–96	1.32	
From balance of 1896–97	4,201.93	
From appropriation for 1897–98	160,000.00	
		164,203.25
Printing—National Museum:		
From balance of 1896–97	8.33	
From appropriation for 1897–98	12,000.00	
		12,008.33
Furniture and fixtures—National Museum:		
From balance of 1895–96	0.20	
From balance of 1896–97	1,801.07	
From appropriation for 1897–98	30,000.00	
		31,801.27
Heating and lighting, etc.—National Museum:		
From balance of 1895–96	0.42	
From balance of 1896–97	742.11	
From appropriation for 1897–98	14,000.00	
		14,742.53
Rent of workshops, etc.—National Museum:		
From balance of 1896–97	0.08	
From appropriation for 1897–98	2,000.00	
		2,000.08
Postage—National Museum:		
From appropriation for 1897–98		500.00
Building repairs—National Museum:		
From balance of 1895–96	1.38	
From balance of 1896–97	115.25	
From appropriation for 1897–98	4,000.00	
		4,116.63
Galleries—National Museum:		
From balance for 1896–97	4,024.35	
From appropriation for 1897–98	8,000.00	
		12,024.35
Rebuilding sheds, etc.—National Museum:		
From appropriation for 1897–98		2,500.00
Astrophysical Observatory—Smithsonian Institution:		
From balance of 1895–96	56.50	
From balance of 1896–97	2,426.44	
From appropriation for 1897–98	10,000.00	
		12,482.94
National Zoological Park:		
From balance of 1895–96	23.23	
From balance of 1896–97	1,567.03	
From appropriation for 1897–98	55,000.00	
		56,590.26

SUMMARY.

Smithsonian Institution	128,710.72
Exchanges	19,179.66
Ethnology	45,274.56
Preservation of collections	164,203.25

Printing	$12,008.33	
Furniture and fixtures	31,801.27	
Heating and lighting	14,742.53	
Rent of workshop	2,000.08	
Postage	500.00	
Building repairs	4,116.63	
Galleries	12,024.35	
Rebuilding sheds	2,500.00	
Astrophysical Observatory	12,482.94	
National Zoological Park	56,590.26	
		$506,134.58

The committee has examined the vouchers for payment from the Smithsonian income during the year ending June 30, 1898, each of which bears the approval of the Secretary or, in his absence, of the Acting Secretary, and a certificate that the materials and services charged were applied to the purposes of the Institution.

The committee has also examined the accounts of the several appropriations committed by Congress to the Institution, and finds that the balances hereinbefore given correspond with the certificates of the disbursing clerk of the Smithsonian Institution, whose appointment as such disbursing officer has been accepted and his bond approved by the Secretary of the Treasury.

The quarterly accounts current, the vouchers, and journals have been examined and found correct.

Statement of regular income from the Smithsonian fund available for use in the year ending June 30, 1899.

Balance on hand June 30, 1898		$65,803.02
(Including cash from executors of J. H. Kidder)	$5,000.00	
(Including cash from Dr. Alexander Graham Bell)	5,000.00	
	10,000.00	
Interest due and receivable July 1, 1898	27,360.00	
Interest due and receivable January 1, 1899	27,360.00	
Interest, West Shore Railroad bonds, due July 1, 1898	840.00	
Interest, West Shore Railroad bonds, due January 1, 1899	840.00	
		56,400.00
Total available for year ending June 30, 1899		122,203.02

Respectfully submitted.

J. B. Henderson,
Wm. L. Wilson,
Alexander Graham Bell,
Executive Committee.

Washington, D. C., *January 11, 1899.*

ACTS AND RESOLUTIONS OF CONGRESS RELATIVE TO THE SMITHSONIAN INSTITUTION, NATIONAL MUSEUM, ETC.

(In continuation of proceedings noted in previous reports.)

[Fifty-fifth Congress, Second session.]

REGENTS OF SMITHSONIAN INSTITUTION.

Resolved by the Senate and House of Representatives of the United States of America in Congress assembled, That the vacancies in the Board of Regents of the Smithsonian Institution, of the class other than Members of Congress, shall be filled by the appointment of Alexander Graham Bell, a resident of the city of Washington, in place of Gardiner G. Hubbard, of the city of Washington, deceased; and by the reappointment of John B. Henderson, a resident of the city of Washington, and of William Preston Johnston, of Louisiana, whose terms of office expire on January twenty-sixth, eighteen hundred and ninety-eight. (Approved January 24, 1898; Statutes of 1897–98, p. 733.)

LEAVES OF ABSENCE; CONDITION OF BUSINESS.

SEC. 7. That section five of the act making appropriations for legislative, executive, and judicial expenses, approved March third, eighteen hundred and ninety-three, is hereby amended to read as follows:

"Hereafter it shall be the duty of the heads of the several executive departments, in the interest of the public service, to require of all clerks and other employees, of whatever grade or class, in their respective departments, not less than seven hours of labor each day, except Sundays and days declared public holidays by law or Executive order: *Provided*, That the heads of the departments may, by special order, stating the reason, further extend the hours of any clerk or employee in their departments, respectively; but in case of an extension it shall be without additional compensation: *Provided further*, That the head of any department may grant thirty days' annual leave with pay in any one year to each clerk or employee: *And provided further*, That where some member of the immediate family of a clerk or employee is afflicted with a contagious disease and requires the care and attendance of such employee, or where his or her presence in the department would jeopardize the health of fellow-clerks, and in exceptional and meritorious cases, where a clerk or employee is personally ill, and where to limit the annual leave to thirty days in any one calendar year would work peculiar hardship, it may be extended, in the discretion of the head of the department, with pay, not exceeding thirty days in any one case or in any one calendar year.

"This section shall not be construed to mean that so long as a clerk or employee is borne upon the rolls of the department in excess of the time herein provided for or granted that he or she shall be entitled to pay during the period of such excessive absence, but that the pay shall stop upon the expiration of the granted leave.

"Hereafter it shall be the duty of the head of each executive department to require monthly reports to be made to him as to the condition of the public business in the several bureaus or offices of his department at Washington; and in each case where such reports disclose that the public business is in arrears, the head of the department in which such arrears exist shall require, as provided herein, an extension of the hours of service to such clerks or employees as may be necessary to bring up such arrears of public business." (Legislative, executive, and judicial act approved March 15, 1898; Statutes of 1897–98, chap. 68, p. 316.)

Nothing contained in section seven of the act making appropriations for legislative, executive, and judicial expenses of the Government for the fiscal year eighteen hundred and ninety-nine, approved March fifteenth, eighteen hundred and ninety-eight, shall be construed to prevent the head of any executive department from granting thirty days' annual leave with pay in any one year to a clerk or employee, notwithstanding such clerk or employee may have had during such year not exceeding thirty days' leave with pay on account of sickness as provided in said section seven. (Deficiency appropriation act July 7, 1898; Statutes of 1897–98, chap. 571, p. 653.)

QUARTERLY REPORT ON CONDITION OF PUBLIC BUSINESS.

Hereafter it shall be the duty of the head of each executive department, or other Government establishment at the seat of Government not under an executive department, to make at the expiration of each quarter of the fiscal year a written report to the President as to the condition of the public business in his executive department or Government establishment, and whether any branch thereof is in arrears. (Section 7, legislative, executive, and judicial appropriation act, approved March 15, 1898; Statutes of 1897–98, p. 317.)

PURCHASE OF BOOKS OF REFERENCE.

That hereafter law books, books of reference, and periodicals for use of any executive department, or other Government establishment not under an executive department, at the seat of Government, shall not be purchased or paid for from any appropriation made for contingent expenses or for any specific or general purpose unless such purchase is authorized and payment therefor specifically provided in the law granting the appropriation. (Section 3, legislative, executive, and judicial appropriation act, approved March 15, 1898; Statutes of 1897–98, p. 316.)

CATALOGUE OF SCIENTIFIC LITERATURE.

International Conference on a Catalogue of Scientific Literature: For expenses of a delegate to the International Conference on a Catalogue of Scientific Literature, to be held at London during the present year, not exceeding five hundred dollars. (Deficiency appropriation act, July 7, 1898; Statutes of 1897–98, chap. 571, p. 653.)

NATIONAL MUSEUM.

For cases, furniture, fixtures, and appliances required for the exhibition and safe-keeping of the collections of the National Museum, including twenty thousand dollars for furnishing new galleries and including salaries or compensation of all necessary employees, thirty-five thousand dollars.

For expense of heating, lighting, electrical, telegraphic, and telephonic service for the National Museum, fourteen thousand dollars.

For continuing the preservation, exhibition, and increase of the collections from the surveying and exploring expeditions of the Government, and from other sources, including salaries or compensation of all necessary employees, one hundred and sixty-five thousand dollars, of which sum five thousand five hundred dollars may be used for necessary drawings and illustrations for publications of the National Museum.

For purchase of books, pamphlets, and periodicals for reference in the National Museum, two thousand dollars.

For repairs to buildings, shops, and sheds, National Museum, including all necessary labor and material, four thousand dollars.

For rent of workshops and temporary storage quarters for the National Museum, four thousand five hundred dollars.

For postage stamps and foreign postal cards for the National Museum, five hundred dollars.

For the continuation of the construction of galleries in the National Museum building, under the direction of the Superintendent of the Congressional Library building and grounds, in accordance with the approval of the Secretary of the Smithsonian Institution, and for the building of skylights above galleries in the four courts, and the erection of a ventilator upon the roof of the Lecture Hall, ten thousand dollars.

For purchase of two thousand nine hundred volumes, eighteen thousand pamphlets, and one thousand eight hundred portraits, autographs, and engravings relating to museums, exhibitions, and natural history, library of the late G. Brown Goode, five thousand dollars. (Sundry civil act, July 1, 1898; Statutes of 1897–98, chap. 546, p. 608.)

PRINTING AND BINDING FOR NATIONAL MUSEUM.

For the Smithsonian Institution, for printing labels and blanks for the "Bulletins" and annual volumes of the "Proceedings" of the National Museum, the editions of which shall not be less than three thousand copies, and binding in half turkey, or material not more expensive, scientific books and pamphlets presented to and acquired by the National Museum Library, seventeen thousand dollars. (Sundry civil act, July 1, 1898; Statutes of 1897–98, chap. 546, p. 647.)

INTERNATIONAL EXCHANGES.

For expenses of the system of international exchanges between the United States and foreign countries, under the direction of the Smithsonian Institution, including salaries or compensation of all necessary employees, and the purchase of necessary books and periodicals, twenty-one thousand dollars. (Sundry civil act for 1899, July 1, 1898; Statutes of 1897–98, chap. 546, p. 608.)

AMERICAN ETHNOLOGY.

For continuing ethnological researches among the American Indians, under the direction of the Smithsonian Institution, including salaries or compensation of all necessary employees, and the purchase of necessary books and periodicals, fifty thousand dollars, of which sum not exceeding one thousand dollars may be used for rent of building. (Sundry civil act for 1899, July 1, 1898; Statutes of 1897–98, chap. 546, p. 608.)

For payment of the outstanding accounts incurred during the fiscal year ended June thirtieth, eighteen hundred and ninety-seven, under the appropriation "North American ethnology, Smithsonian Institution," and which are set forth on page five of House document numbered three hundred and nineteen, of this session, four hundred and sixty-six dollars and fifty cents. (Deficiency appropriation act for 1898; Statutes of 1897–98, chap. 571, p. 662.)

ASTROPHYSICAL OBSERVATORY.

For maintenance of astrophysical observatory, under the direction of the Smithsonian Institution, including salaries of assistants, the purchase of necessary books and periodicals, apparatus, printing and publishing results of researches, not exceeding one thousand five hundred copies, and miscellaneous expenses, ten thousand dollars. (Sundry civil act, July 1, 1898; Statutes of 1897–98; chap. 546, p. 608.)

That the secretary of the Smithsonian Institution is hereby authorized to apply any unexpended balance of the appropriation for the astrophysical observatory, Smithsonian Institution, for the fiscal year ending June thirtieth, eighteen hundred and ninety-eight, to the improvement of the building used for the purposes of the said observatory, and the same is hereby reappropriated and made available for expenditure during the fiscal year eighteen hundred and ninety-nine for the object set forth. (Deficiency appropriation act for 1898; Statutes of 1897–98, chap. 571, p. 662.)

NATIONAL ZOOLOGICAL PARK.

For continuing the construction of roads, walks, bridges, water supply, sewerage and drainage; and for grading, planting, and otherwise improving the grounds; erecting and repairing buildings and inclosures; care, subsistence, purchase, and transportation of animals, including salaries or compensation of all necessary employees, the purchase of necessary books and periodicals, and general incidental expenses not otherwise provided for, sixty-five thousand dollars; one-half of which sum shall be paid from the revenues of the District of Columbia and the other half from the Treasury of the United States; and of the sum hereby appropriated five thousand dollars shall be used for continuing the entrance into the Zoological Park from Woodley Lane, and opening driveway into Zoological Park, from said entrance along the bank of Rock Creek. (Sundry civil act approved July 1, 1898; Statutes of 1897–98, chap. 546, p. 608.)

For the purpose of opening Cathedral avenue in accordance with the highway extension plans, the Secretary of the Interior is hereby authorized and directed to convey all right and title of the United States in and to a parcel of land bounded on the north by block two of the subdivision called Meridian Hill, and on the east by the east line of said block two extended southward, and on the west by the east line of Sixteenth street west as said line is now extended and laid down through said block two, and on the south by a line parallel to W street of the city of Washington and distant ninety feet north from the south line of said W street, to the parties owning a good and unincumbered title in fee simple to lots numbered twenty-two to twenty-nine, both inclusive, in block numbered five of the subdivision called Woodley Park, in the District of Columbia, containing about one hundred and three thousand five hundred square feet of land, and adjoining the land of the United States embraced in the Zoological Park, upon the conveyance by said parties of the said lots to the United States: *Provided*, That said lots in said Woodley Park, when so conveyed to the United States as aforesaid, shall become part of the said Zoological Park and shall be subject to the inclusion of so much of the same on said Cathedral avenue as may be necessary for the purpose of opening the said avenue. (Sundry civil act approved July 1, 1898; Statutes of 1897–98, chap. 546, p. 616.)

INTERNATIONAL FISHERIES EXPOSITION IN NORWAY.

JOINT RESOLUTION Accepting the invitation of the Government of Norway to take part in an International Fisheries Exposition to be held at the city of Bergen, Norway, from May to September, anno Domini eighteen hundred and ninety-eight.

Whereas the United States have been duly invited by the Government of Norway to take part in an International Fisheries Exposition to be held at the city of Bergen, Norway, from May sixteenth to September thirtieth, anno Domini eighteen hundred and ninety-eight, which Exposition will also include national sections for industries, agriculture, and the fine arts: Therefore,

Resolved by the Senate and House of Representatives of the United States of America in Congress assembled, That said invitation is accepted, and that the Commissioner of Fish and Fisheries is hereby directed, in person, or by a deputy to be appointed by the President of the United States, and whose compensation if not in the public service shall not exceed two thousand five hundred dollars, including personal and traveling expenses, to represent the United States at said Exposition, and to cause a suitable and proper exhibition and display to be made at said Exposition of the food-fishes of the United States, and the methods of catching, salting, curing, and preserving the same, and of the implements and appliances used in carrying on the fishery industries of the United States, and to this end may, at his discretion, use any portion of the collection in the National Museum at said Exposition.

That the sum of twenty thousand dollars, or so much thereof as may be necessary, is hereby appropriated, out of any money in the United States Treasury not otherwise appropriated, to be immediately available, and to be expended under the direction of the Secretary of State, to pay all the expenses and costs of representing the United States at said Exposition, as aforesaid, and to pay all the costs and expenses and outlays pertaining or incident to the making and carrying on of the exhibition and display aforesaid at said Exposition: *Provided*, That the total expenses and liabilities incurred under this resolution shall not exceed the sum of twenty thousand dollars.

That the said Commissioner, or his deputy, is hereby directed to make a full report to the Department of State of the participation of the United States in said Exposition, and of all the information and results acquired and obtained at or by means of said Exposition touching the fishery industry throughout the world. (Approved January 25, 1898; Statutes of 1897–98, p. 733.)

JOINT RESOLUTION Accepting the invitation of the Government of Norway to take part in an International Fisheries Exposition to be held at the city of Bergen, Norway, from May to September, anno Domini eighteen hundred and ninety-eight.

Whereas the United States have been duly invited by the Government of Norway to take part in an International Fisheries Exposition to be held at the city of Bergen, Norway, from May sixteenth to September thirtieth, anno Domini eighteen hundred and ninety-eight,

which exposition will also include national sections for industries, agriculture, and the fine arts: Therefore,

Resolved by the Senate and House of Representatives of the United States of America in Congress assembled, That said invitation is accepted, and that the Commissioner of Fish and Fisheries is hereby directed, in person, or by a deputy to be appointed by the President of the United States, and whose compensation if not in the public service shall not exceed two thousand five hundred dollars, including personal and traveling expenses, to represent the United States at said exposition, and to cause a suitable and proper exhibition and display to be made at said exposition of the food fishes of the United States, and the methods of catching, salting, curing, and preserving the same, and of the implements and appliances used in carrying on the fishery industries of the United States, and to this end may, with the consent of the Secretary of the Smithsonian Institution, use any portion of the fisheries collection in the National Museum at said exposition.

That the sum of twenty thousand dollars, or so much thereof as may be necessary, is hereby appropriated, out of any money in the United States Treasury not otherwise appropriated, to be immediately available, and to be expended under the direction of the Secretary of State, to pay all the expenses and costs of representing the United States at said exposition, as aforesaid, and to pay all the costs and expenses and outlays pertaining or incident to the making and carrying on of the exhibition and display aforesaid at said exposition: *Provided*, That the total expenses and liabilities incurred under this resolution shall not exceed the sum of twenty thousand dollars.

That the said Commissioner, or his deputy, is hereby directed to make a full report to the Department of State of the participation of the United States in said exposition, and of all the information and results acquired and obtained at or by means of said exposition touching the fishery industry throughout the world. (Approved, February 17, 1898; Statutes of 1897–98, p. 734.)

That the joint resolution accepting the invitation of the Government of Norway to take part in an International Fisheries Exposition to be held at the city of Bergen, Norway, from May to September, anno Domini eighteen hundred and ninety-eight, approved January twenty-fifth, eighteen hundred and ninety-eight, be, and the same is hereby, repealed. (Deficiency appropriation act, approved July 7, 1898; Statutes of 1897–98, chap. 571, p. 653.)

OMAHA EXPOSITION.

That the paragraph in the "Act making appropriation for sundry civil expenses of the Government for the fiscal year ending June thirtieth, eighteen hundred and ninety-eight, and for other purposes," approved June fourth, eighteen hundred and ninety-seven, making appropriation of two hundred thousand dollars for construction of building or buildings and for Government exhibit, be amended in the second line thereof by adding after the word "including," the following words: the selection, purchase, preparation, installation, care and. (Urgent deficiency act, approved January 28, 1898; Statutes of 1897–98, p. 236.)

JOINT RESOLUTION Extending limit of cost of the Government building or buildings at the Transmississippi and International Exposition at Omaha, Nebraska, and reducing cost of Government exhibit.

Resolved by the Senate and House of Representatives of the United States of America in Congress assembled, That the Secretary of the Treasury be, and he is hereby, authorized and directed to cause to be constructed and completed, at an additional cost not to exceed ten thousand dollars, the Government building at the Transmississippi and International Exposition at Omaha, Nebraska, as shown and called for by the plans, drawings, and specifications on which bids were taken for its erection, and so forth; and that the Secretary of the Treasury be, and he is hereby, further authorized and directed to cause to be erected at said exposition a building for an exhibit of the United States Life-Saving Service, at a cost not to exceed for said building the sum of two thousand five hundred dollars; and to enable the Secretary of the Treasury to give effect to, and execute the provisions of, this act, the limit of cost of the Government building or buildings authorized to be erected at said exposition is hereby extended from fifty thousand dollars to sixty-two thousand five hundred dollars; and the cost of the Government exhibit at said exposition is hereby reduced from one hundred fifty thousand dollars to one hundred thirty-seven thousand five hundred dollars. (Approved, December 18, 1897.)

JOINT RESOLUTION Authorizing the Secretary of the Treasury to rent lighting apparatus for Government building at Transmississippi and International Exposition.

Resolved by the Senate and House of Representatives of the United States of America in Congress assembled, That the Secretary of the Treasury be, and he is hereby, authorized to rent electric wiring and lamps for the lighting of the exterior of the building for the Government exhibit at the Transmississippi and International Exposition at Omaha, Nebraska, if, in his judgment, such course will be less expensive than to wire the building and furnish lamps therefor; the expense thereof to be paid from the unexpended balance of the appropriation for the construction of said building. (Approved, May 18, 1898; Statutes of 1897–98, p. 743.)

PARIS EXPOSITION.

The President, by and with the advice and consent of the Senate, shall appoint a commissioner-general to represent the United States at the exposition to be held in Paris, France, commencing April fifteenth and closing November fifth, nineteen hundred, and, under the general direction of the President to make all needful rules and regulations in reference to the contributions from the United States, subject to the approval of the President, and to control the expenditures incident to and necessary for the proper installation and exhibit thereof; and the President, by and with the advice and consent of the Senate, shall also appoint an assistant commissioner-general, who shall assist and act under the direction of the commissioner-general, and shall perform the duties of the commissioner-general in case of his death, disability, or temporary absence; and a secretary, who shall act as disbursing agent and shall perform such duties as may be assigned to him by the commissioner general, shall render his accounts quarterly to the proper accounting officers of the Treasury, and shall give bond in such sum as the Secretary of the Treasury may require. The President, by and with the advice and consent of the Senate, shall also appoint twelve commissioners, who shall be subject to the direction and control of the commissioner-general and perform from time to time such service as he shall require. The commissioner-general shall employ such number of experts as may be needed, having special attainments in regard to the subjects of the group or groups in said exposition to which they may be assigned, respectively, and he may employ from time to time such other experts as he may deem necessary in the preparation and installation of such exhibits. The commissioner-general shall be paid a salary of eight thousand dollars per annum; the assistant commissioner-general a salary of six thousand dollars per annum; and the secretary a salary of four thousand five hundred dollars per annum; which said sums shall be in lieu of all personal expenses other than actual traveling expenses while engaged in exposition work; and the terms of service of the commissioner-general, assistant commissioner-general, and secretary shall not exceed three years. The commissioners herein provided for shall serve during the entire calendar year nineteen hundred, and they shall be paid for such service three thousand dollars each, which payments shall be in full for all compensation and personal and traveling expenses. The necessary expenses herein authorized, and expenses for the proper installation and care of exhibits, together with all other expenses that may be authorized by the commissioner-general incident to the participation of the United States in said exposition, are hereby limited to the sum of not exceeding six hundred and fifty thousand dollars, including not exceeding eighty-five thousand dollars for clerk hire in the United States and in Paris. The Secretary of Agriculture is hereby authorized to prepare suitable exhibits of agricultural products of the States and Territories of the United States, including those mentioned in groups seven, eight, and ten of the plan of said exposition, and shall exhibit the same under the direction and control of the commissioner-general, the total expenses of the said exhibits not to exceed in the aggregate seventy-five thousand dollars, to be paid out of the aforesaid sum of six hundred and fifty thousand dollars; and reports respecting such exhibits, printed in the English, French, and German languages, shall accompany such exhibits, as the commissioner-general may direct. All officers and employees of the Executive Departments and of the Fish Commission and of the Smithsonian Institution, in charge of or responsible for the safe-keeping of exhibits belonging to the United States, may permit such exhibits to pass out of their possession for the purpose of being transported to and from and exhibited at said exposition, as may be requested by the commissioner-general, whenever authorized to do so, respectively, by the heads of the Departments and the Commisioner of Fish and Fisheries and the Secretary of the Smithsonian Institution; such exhibits and articles to be returned to the said respective Departments to which they belong at the close of the exposition. It shall be the duty of the commissioner-general to report to the President, for transmission to Congress at the beginning of each regular session, a detailed statement of the expenditures incurred hereunder during the twelve months preceding; and the commissioner-general is hereby required, within four months after the close of said exposition, to make full report of the results thereof, as herein required, which report shall be prepared and arranged with a view to concise statement and convenient reference, and when printed shall not exceed six volumes octavo, containing an average of not exceeding one thousand pages. Toward the expenses herein authorized, incident to the participation of the United States in said exposition, there is hereby appropriated the sum of two hundred thousand dollars, to be immediately available, and to remain available until expended, of which amount the sum of twenty thousand dollars may be used by the Secretary of Agriculture in the preparation of the agricultural exhibit herein provided for. (Sundry civil act, approved July 1, 1898; Statutes of 1897–98, chap. 546, p. 645.)

BUFFALO EXPOSITION.

JOINT RESOLUTION Regarding the holding of a Pan-American Exposition in the year nineteen hundred and one upon Cayuga Island, between the cities of Buffalo and Niagara Falls, in the State of New York, to illustrate the development of the Western Hemisphere during the nineteenth century.

Whereas there has been duly incorporated, under the laws of the State of New York, by citizens of said State, a company organized for the purpose and with the object of preparing and holding a Pan-American Exposition on Cayuga Island, near Niagara Falls, New York, in the year nineteen hundred and one, to fittingly illustrate the marvelous development of the Western Hemisphere during the nineteenth century and to appropriately celebrate the opening of the twentieth century by a demonstration of the reciprocal relations existing between the American Republics and colonies; and

Whereas the legislature of the State of New York has, by unanimous vote, memorialized Congress to encourage the holding of said Pan-American Exposition; and

Whereas the proposed exposition, being confined in its scope to the Western Hemisphere, would unquestionably be of vast benefit to the commercial interests of the countries of North, South, and Central America: Therefore,

Resolved by the Senate and House of Representatives of the United States of America in Congress assembled, That the proposed Pan-American Exposition to be held on Cayuga Island, between the cities of Buffalo and Niagara Falls, in the State of New York, in the year nineteen hundred and one, merits the encouragement and approval of Congress and of the people of the United States.

SEC. 2. That all articles which shall be imported from foreign countries for the purpose of exhibition at said exposition shall be admitted free of duty, customs fees, or charges, under such regulations as the Secretary of the Treasury shall prescribe; but it shall be lawful during said exposition to sell for delivery at the close thereof any goods or property imported and actually on exhibition therein, subject to such regulations for the security of the revenue as the Secretary of the Treasury shall prescribe: *Provided*, That all such articles when sold or withdrawn for consumption shall be subject to the duty, if any, imposed upon such articles by the revenue laws in force at the date of their importation and to the terms of the tariff laws in force at that time: *And provided further*, That all necessary expenses incurred, including salaries of customs officials in charge of imported articles, shall be paid to the Treasury of the United States by the Pan-American Exposition Company, under regulations to be prescribed by the Secretary of the Treasury.

SEC. 3. That in the passage of this joint resolution the United States does not assume any liability of any kind whatever, and does not become responsible in any manner for any bond, debt, contract, expenditure, expense, or liability of the said exposition company, its officers, agents, servants, or employees, or incident to or growing out of said exposition. (Approved, July 8, 1898; Statutes of 1897–98, p. 752.)

REPORT

OF

S. P. LANGLEY,

SECRETARY OF THE SMITHSONIAN INSTITUTION,

FOR THE YEAR ENDING JUNE 30, 1898.

To the Board of Regents of the Smithsonian Institution.

GENTLEMEN: I have the honor to present herewith my customary report, showing the operations of the Institution during the year ending June 30, 1898, including the work placed under its direction by Congress in the United States National Museum, the Bureau of American Ethnology, the International Exchanges, the National Zoological Park, and the Astrophysical Observatory.

Following the precedent of several years, I have in the body of this report given a general account of the affairs of the Institution and its bureaus, while the appendix presents more detailed statements by the persons in direct charge of the different branches of the work. Independently of this, the operations of the National Museum are fully treated in a separate volume of the Smithsonian Report, prepared by Acting Assistant Secretary C. D. Walcott, and the report of the work of the Bureau of American Ethnology constitutes a volume prepared under the supervision of Major J. W. Powell, the Director of that Bureau.

THE SMITHSONIAN INSTITUTION.

THE ESTABLISHMENT.

I have to record three changes during the year, caused by the resignation of Secretary of State John Sherman, Attorney-General Joseph McKenna, and Postmaster-General James A. Gary, who were succeeded by the Hon. William R. Day, the Hon. John W. Griggs, and the Hon. Charles Emory Smith. As organized at the end of the fiscal year the Establishment consisted of the following ex officio members:

William McKinley, *President of the United States.*
Garret A. Hobart, *Vice-President of the United States.*
Melville W. Fuller, *Chief Justice of the United States.*
William R. Day, *Secretary of State.*
Lyman J. Gage, *Secretary of the Treasury.*
Russell A. Alger, *Secretary of War.*
John W. Griggs, *Attorney-General.*
Charles Emory Smith, *Postmaster-General.*
John D. Long, *Secretary of the Navy.*
Cornelius N. Bliss, *Secretary of the Interior.*
James Wilson, *Secretary of Agriculture.*

The Establishment, which formerly held occasional meetings, has not been assembled for some time.

THE BOARD OF REGENTS.

In accordance with a resolution of the Board of Regents adopted January 8, 1890, by which its annual meeting occurs on the fourth Wednesday of each year, the Board met on January 26, 1898, at 10 o'clock a. m. The journal of its proceedings will be found, as hitherto, in the annual report of the Board to Congress, though reference is made later on in this report to several matters upon which action was taken at that meeting.

The Secretary announced to the Board the death of Mr. Gardiner Greene Hubbard, a regent, and after appropriate remarks by members of the Board, resolutions were unanimously adopted by a rising vote, which will be found under the heading Necrology.

Dr. Alexander Graham Bell was appointed a regent (to fill the vacancy caused by the death of Mr. Hubbard) by joint resolution, approved by the President of the United States on January 24, 1898. Gen. John B. Henderson and Dr. William Preston Johnston were reappointed by the same joint resolution. Senator Morrill was reappointed by the President of the Senate on March 15, 1897, and the Hon. Joseph Wheeler, the Hon. R. R. Hitt, and the Hon. Robert Adams, jr. (Representatives), were reappointed by the Speaker of the House on December 22, 1897.

Mr. Bell was elected a member of the executive committee, of which General Henderson was reelected chairman.

The Secretary presented his annual report of operations to June 30, 1897, which was accepted. Reports were also presented by General Henderson as chairman of both the executive and the permanent committees.

The Secretary announced his acceptance of the resignation of Prof. Charles D. Walcott as Acting Assistant Secretary in Charge of the

National Museum, and the Board passed a resolution modifying the terms of the appointment of Mr. Richard Rathbun as Assistant Secretary, so that his services might be utilized wherever it was deemed best for the interests of the Institution.

The report of a special committee, of which Mr. Hubbard had been chairman, was submitted by General Henderson, pointing out the need for the National Museum of a new building, as well as an increase in the scientific staff and a definite purchasing fund; for the Bureau of American Ethnology the desirability of the passage of a law declaring archæological sites on the public domain public monuments; and for the National Zoological Park the need of greater facilities for the purchase and housing of animals.

With regard to the recommendation of the desirability of the passage of a law declaring archæological sites on the public domain public monuments, a form of proposed legislation has been prepared which may later be brought to the attention of the Congressional Regents in their legislative capacity.

There was also a further suggestion of the form which the reports of bureau officers on the property in their charge should assume, all of which matters have had the Secretary's attention.

At the beginning of the Spanish-American war the Hon. Joseph Wheeler, a regent, was appointed major-general of United States Volunteers, and went with the army to Cuba, where his service is matter of public record. Dr. Andrew D. White, a regent, has been appointed ambassador to Germany, and Dr. James B. Angell, another regent, minister to Turkey. These gentlemen are still regents, though the Institution has during the year been deprived of their valued services.

ADMINISTRATION.

As the business of the Institution itself and of the various Government bureaus under its direction increases from year to year, the question of administration and of a proper division of its cost among the various bureaus becomes more pressing. It has been the purpose of the Secretary to delegate to those in immediate charge of the bureaus as much authority as is consistent with his responsibilities to the Board of Regents and to Congress. The gradual growth of the bureaus both in number and importance has thrown into the Secretary's office a very considerable amount of clerical labor pertaining almost exclusively to Government work, and while the cost of clerical service for this central control has been divided among the bureaus where practicable, yet the limited income of the Institution must be drawn upon in larger measure than seems proper until a suitable time for the organization of a force, paid from an appropriation specifically for this purpose. The Board has already authorized the Secretary to call upon Congress for such an appropriation, but each year obstacles have arisen rendering action inexpedient.

FINANCES.

At the beginning of the fiscal year, July 1, 1897, the unexpended balance, as stated in my last annual report, was $61,532.50. The total receipts for the year were $67,178.22, being $56,400 derived from the interest on the permanent fund in the Treasury and elsewhere, and $10,778.22 received from miscellaneous sources.

The disbursements for the year amounted to $62,907.70, the details of which are given in the report of the executive committee. The balance remaining to the credit of the Secretary on June 30, 1898, for the expenses of the Institution, was $65,803.02, which includes $10,000 referred to in previous reports, $5,000 of which was received from the estate of Dr. J. H. Kidder, and a like sum from Dr. Alexander Graham Bell, the latter a gift made personally to the Secretary to promote certain physical researches. This latter sum was, with the donor's consent, deposited by the Secretary to the credit of the current funds of the Institution.

This balance also includes the interest accumulated on the Hodgkins and other funds, which is held against certain contingent obligations, besides relatively considerable sums held to meet obligations which may be expected to mature as a result of various scientific investigations and publications in progress.

The permanent funds of the Institution are as follows:

Bequest of Smithson, 1846		$515,169.00
Residuary legacy of Smithson, 1867		26,210.63
Deposits from savings of income, 1867		108,620.37
Bequest of James Hamilton, 1875	$1,000.00	
Accumulated interest on Hamilton fund, 1895	1,000.00	
		2,000.00
Bequest of Simeon Habel, 1880		500.00
Deposits from proceeds of sale of bonds, 1881		51,500.00
Gift of Thomas G. Hodgkins, 1891		200,000.00
Portion of residuary legacy, T. G. Hodgkins, 1894		8,000.00
Total permanent fund		912,000.00

The Regents also hold certain approved railroad bonds, forming part of the fund established by Mr. Hodgkins for investigations of the properties of atmospheric air.

By act of Congress approved by the President March 12, 1894, an amendment was made to section 5591 of the Revised Statutes, the fundamental act organizing the Institution, as follows:

> The Secretary of the Treasury is authorized and directed to receive into the Treasury, on the same terms as the original bequest of James Smithson, such sums as the Regents may, from time to time, see fit to deposit, not exceeding with the original bequest the sum of $1,000,000: *Provided*, That this shall not operate as a limitation on the power of the Smithsonian Institution to receive money or other property by gift, bequest, or devise, and to hold and dispose of the same in promotion of the purposes thereof.

Under this section, 5591 of the Revised Statutes, modified as above noted, the above fund of $912,000 is deposited in the Treasury of the United States, bearing interest at 6 per cent per annum, the interest alone being used in carrying out the aims of the Institution.

During the fiscal year 1897–98 Congress charged the Institution with the disbursement of the following appropriations:

International Exchanges	$19,000
North American Ethnology	45,000
United States National Museum:	
Preservation of collections	160,000
Furniture and fixtures	30,000
Heating and lighting	15,097
Postage	500
Repairs to buildings	4,000
Rent of workshops	2,000
Galleries	8,000
Rebuilding sheds	2,500
Printing	12,000
National Zoological Park	55,000
Astrophysical Observatory	10,000

The executive committee has examined all the vouchers for disbursements made during the fiscal year, and a detailed statement of the receipts and expenditures will be found reported to Congress, in accordance with the provisions of the sundry civil acts of October 2, 1888, and August 5, 1892, in a letter addressed to the Speaker of the House of Representatives.

The vouchers for all of the expenditures from the Smithsonian fund proper have been likewise examined and their correctness certified to by the executive committee, whose statement will be published, together with the accounts of the funds appropriated by Congress, in that committee's report.

The estimates for the fiscal year ending June 30, 1899, for carrying on the Government interests under the charge of the Smithsonian Institution and forwarded as usual to the Secretary of the Treasury were as follows:

International Exchanges	$24,000
American Ethnology	50,000
National Museum:	
Preservation of collections	180,000
Furniture and fixtures	35,000
Heating and lighting	15,000
Postage	500
Galleries	10,000
Repairs to buildings	8,000
Rent of workshops	4,500
Books	2,000
Illustrations for publications	5,000
Building for workshops and storage	50,000
Library of late G. Brown Goode	5,000

National Museum—Continued.	
Bebb Herbarium [1]	$5,000
Printing	17,000
National Zoological Park	75,000
Astrophysical Observatory	10,000

The appropriations made by Congress for the fiscal year 1899 were as follows:

International Exchanges, Smithsonian Institution, 1899	$21,000
American Ethnology, Smithsonian Institution, 1899	50,000
Astrophysical Observatory, Smithsonian Institution, 1899	10,000
National Museum, Smithsonian Institution, 1899:	
Furniture and fixtures	35,000
Heating and lighting	14,000
Preservation of collections	165,000
Postage	500
Galleries	10,000
Books	2,000
Rent of workshops	4,500
Building repairs	4,000
Purchase of library of the late G. Brown Goode	5,000
National Zoological Park, 1899	65,000

HAMILTON FUND.

The original amount of $1,000, the bequest of Mr. James Hamilton, of Pennsylvania, received by the Institution in 1874, was increased in 1895 to $2,000 by the addition of accumulated interest under authority given by the Regents in their meeting of January 23, 1895, the sum of $150 expended from the income of fund in 1876 for explorations having been refunded. The present income, together with interest accumulated since 1895, seems to warrant some definite application of the interest on the bequest, and I am now considering a plan of lectureships in accordance with the testator's purpose.

AVERY FUND.

Concerning the Avery fund I have to report that by a decision of the Supreme Court of the United States the Institution has obtained a clear title to the property on Capitol Hill claimed by the heirs of Mrs. Avery. The executrix of the estate has settled her accounts, and a small balance in cash has been paid to the Institution. Certain stocks and bonds are held by a trust company, the income to be paid over to Miss Avery during her lifetime, and upon her death the principal is to be paid to the Institution. The Institution also holds some small pieces of real estate which it is not deemed wise to dispose of at present. The Commissioners of the District of Columbia have freed this property from all claim for taxes.

It may be recalled that the testator, while leaving his property absolutely at the disposal of the Regents, expressed a wish that it might be

[1] Item withdrawn, as the collection had been sold.

made useful in promoting researches on the Ether, after certain mathematical and phonetic publications and certain researches connected with a special form of telescope had been made. The moneys received from the estate are as yet too small to carry out any part of this purpose but the last.

BUILDINGS.

No alterations were made in the Smithsonian Building during the year except such slight repairs as seemed necessary to keep it in good condition. The space in the rear of the building, however, which for a number of years had been occupied by unsightly and dangerous storage sheds and workshops, has been cleared of these and graded into a lawn, thus very greatly improving the surroundings.

In the park south of the building, and at a distance sufficient to prevent annoyance, there has been erected a temporary wooden building of two stories for the use of the taxidermists and for other purposes.

The investigations being prosecuted in the Astrophysical Observatory requiring more space than is available in the old structure, plans have been approved and some progress made toward the erection of some very simple additions authorized by Congress at its last session by a clause permitting the expenditure for this purpose of an unexpended balance of the annual appropriation for the maintenance of the observatory.

Four additional galleries have been erected in the Museum Building, three for exhibition purposes and one to serve as an increase for the quarters for the Library, thus adding 6,650 square feet to the floor space of the Museum, 6,040 square feet of which is available for exhibition purposes.

RESEARCH.

The promotion of original research has always been one of the principal functions of the Institution. Investigations in the anthropological, biological, and geological divisions of science have been extensively carried on through the departments of the National Museum, and in the Bureau of American Ethnology there have also been special inquiries into Indian customs and languages. These lines of research being well represented by its bureaus, it has remained for the Institution proper to devote its energies more especially to some of the physical sciences.

The Secretary himself has carried on researches in the solar spectrum, which, by the active assistance of the Aid in charge, have produced results now shortly to be published. They are believed to be important and are referred to in another portion of this report.

The Secretary has not wholly discontinued the studies which he has made in regard to aerodromic experiments, and it is perhaps not improper that he should state that these have attracted the attention of other departments so far that during the war with Spain a commission was directed by the Secretaries of War and the Navy to inquire into them with a view of their possible utility in war. This is not the place to state the results of these inquiries.

The Secretary desires to repeat, however, that his time is almost solely given to administrative work, and that what he has been able to do in these directions has been done largely in hours which he might consider his own.

In addition, some very important investigations have been made and others are in progress, by specialists, in the fundamental laws of sound, of gases, the upper atmosphere, and on impure air and other important questions, which are mentioned somewhat more in detail under the heading of the Hodgkins fund.

HODGKINS FUND.

Although the Hodgkins fund competition announced by the Institution in the widely distributed circular of March 31, 1893, was definitely closed so long ago as December 31, 1894, a very general interest is still expressed in the subject, and specialists in our own and other countries not infrequently forward copies of their original published memoirs as contributions to the Hodgkins fund library of the Institution.

Frequent applications for grants are received, and, notwithstanding the fact that the limitations on the use of the fund do not permit it to be employed for the support of an investigation, unless under the exceptional conditions of the first published announcement, it has still been found practicable to approve several awards during the past year.

As noted in my last report, in July, 1897, an additional grant of $400 was made to Mr. A. Lawrence Rotch, of the Blue Hill Meteorological Observatory, Readville, Mass., and in the following October a further grant of $250 was approved to Mr. Rotch. These sums are to be devoted to experiments with automatic kites, for determining, by means of self-recording instruments, meteorological data in atmospheric strata inaccessible except by some mechanical method of exploring the atmosphere, and it will be of possible interest to the Board to learn that during the past year, and (to slightly anticipate), shortly after its close, experiments of remarkable success and interest have been made by Mr. Rotch, and, among others, that kites have been flown to the unprecedented height of 11,086 feet above the station, carrying up with them meteorological instruments which recorded the height, the pressure of the wind, the dew point, and other facts of interest at these great altitudes.

Those who remember the situation of Blue Hill, one of the highest landmarks on the Atlantic coast north of the southern shores of the Gulf, and the aspect of the hills, blue with the distance from which they take their name, may be struck by the certainly notable fact that in these experiments the kites sent up from Blue Hill, and held there at the station, were occasionally directly over the distant ocean.

November 1, 1897, a grant of $500 was made to Prof. William Hallock, of Columbia University, New York City, for an investigation having for its object the complete analysis of a particle of air under the influence of articulate sounds, thus contributing a study of the atmosphere in one of its most important functions, that of a conveyer of speech.

In February, 1898, a final grant of $250 was made to Drs. Lummer and Pringsheim, of the Physical Institute of the University of Berlin. The investigation begun by them, in 1893, to determine the ratio of the specific heats, at constant pressure and volume, for air, oxygen, carbondioxide, and hydrogen, has now so far progressed that the memoir submitted by Drs. Lummer and Pringsheim, noting the results already attained by them, has been published by the Institution in the Smithsonian Contribution to Knowledge.

A German edition of this original memoir, with the consent of the Institution, is to be published by the authors, and it is understood that, if found desirable, their research will be further prosecuted under the direction of the Physikalisch-Technische Reichsanstalt, of Berlin, Professor Dr. Kohlrausch, the president, having courteously signified the readiness of that institution to furnish the means necessary for the purpose.

In February, 1898, an additional grant of $250 was made to Mr. E. C. C. Baly, of University College, London, to enable him to continue his research upon the decomposition of the atmosphere by electricity, and upon the ozonizing of mercury. The report of Mr. Baly, stating the result of these investigations, is now awaited by the Institution.

A grant of $250 to Prof. Arthur G. Webster, of Clark University, Worcester, Mass., was approved in May, 1898, for the continuation of a research on the properties of air in connection with the propagation of sound, special effort being directed to the securing of data relating to the influence of the viscosity of air on expiring or vanishing sounds. An instrument devised by Professor Webster for use in this investigation gives the physical measure of a sound, not only when constant, but when rapidly varying. It is expected that this research will furnish results of high practical value in connection with the question of the acoustics of auditoriums, and will contribute information upon points that have not heretofore been satisfactorily investigated.

A paper embodying the results of the interesting research, described in the Secretary's report for 1894, primarily conducted under a grant from the Hodgkins fund to Dr. J. S. Billings and Dr. S. Weir Mitchell, and continued, under their supervision, by Dr. D. H. Bergey, of the Laboratory of Hygiene, University of Pennsylvania, has been published in the Smithsonian Miscellaneous Collections.

Although the terms of acceptance of the Hodgkins bequest preclude any general allotment of the accruing interest in the way of grants, no request for an appropriation is left unconsidered, and any application for the aid of a promising research in the hands of an investigator who is able to comply with the strict, though not unreasonable, conditions which necessarily govern the expenditure of this fund, is sure of serious consideration.

NAPLES TABLE.

Among the applications for the occupancy of the Smithsonian seat at the Naples table during the years 1897–98, the following have been favorably acted upon:

Dr. Bradley M. Martin, of the University of Chicago, whose work has been chiefly in the field of the algæ, and who has published several papers detailing his researches, was appointed for November, 1897, his period at Naples to be supplemented by additional investigation in the laboratory of Dr. Strasburger, of the University at Bonn.

Dr. H. W. Conn, of the department of biology, Wesleyan University, received the appointment for six weeks early in the year 1898, Dr. Dohrn, the superintendent of the station, kindly arranging for his accommodation, although the Smithsonian table was occupied at that time. The fact that Dr. Dohrn finds himself not only willing, but able, to provide for two or, as in this case, even three students at the Smithsonian table during the same period, is a courtesy much appreciated by the Institution.

Dr. D. M. Mottier, of the State University of Indiana, who wished to supplement his investigations at Bonn and Leipzig by some weeks at Naples, was appointed for the months of March and April, 1898.

Dr. W. T. Swingle, of the United States Department of Agriculture, now honorary custodian of algæ in the United States National Museum, occupied the Smithsonian seat at Naples for an additional month during the spring of 1898.

Dr. J. H. Gerould, of Dartmouth College, who prosecuted his investigations in the laboratory of Professor De Lacaze-Duthiers, at Roscoff, Finisterre, France, during the summer, was appointed to the Smithsonian table at Naples for the month of November, 1898.

Although applications for the privilege of the table are often received far in advance of the period for which occupancy is desired, in order that all investigators may be given an equal opportunity to secure appointment, no application is considered more than six months in advance of the date for which the seat is desired, and no appointment is made for a longer period than six months. An occupant is not, however, debarred from applying for an extension of time or for future reappointment.

It may be repeated here that with a formal application for appointment, made to the Secretary of the Smithsonian Institution, the candidate should submit such credentials as he may desire to have on record, among which should be an outline of his scientific history and a list of his published memoirs. Investigators are expected to make a report to the Institution at the end of their term at the table, or at the end of three months, in case of a six months' occupancy.

During the past year a vacancy in the advisory committee of the Naples table was caused by the death of Dr. Harrison Allen, who represented the Association of American Anatomists. Dr. Theodore Gill, of Washington, has been appointed to fill the vacancy, Dr. G. S. Huntington, of New York, to be held as alternate. During the absence in Europe of Dr. C. W. Stiles, the duties of Secretary of the Committee have been performed by Dr. Albert Hassall, of the Department of Agriculture.

The Secretary is under continued obligation to the committee for valuable aid in the work of examining testimonials and recommending action with regard to applications for the table.

EXPLORATIONS.

In the plan of organization of the Institution, among examples of objects for which appropriations may be made, are cited:

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.

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.[1]

The first grant made by the Institution for scientific exploration and field research was in 1848 to Spencer F. Baird, of Carlisle, for the exploration of the bone caves and the local natural history of southeastern Pennsylvania; and during the half century that has elapsed since the grant to that eminent man, who afterwards became the Secretary of the Institution, every possible encouragement and support has been given to natural history and ethnological explorations in America and throughout the world. The income of the Institution has not permitted the expenditure of large sums for this purpose, but valuable advice and instructions have been freely given to explorers connected with Government and private expeditions, and agents of the Institution have in very many cases participated in these explorations. In recent years a vast amount of such work has been carried on by the bureaus under direction of the Institution, a work made possible by Congressional appropriations for this purpose.

As soon as there seemed a possibility of acquiring new territories as a result of the present Spanish-American war I began formulating plans for exploring the possible new regions, and in my next estimates to be sent to Congress I expect to ask definitely for appropriations under which exploring parties may be sent to them.

It is hardly necessary to recall the lasting impression that the French Government made through the researches of the corps of savants sent along with the expedition to Egypt. It would seem incumbent upon this Government, not only for practical economic purposes, but as a contri-

[1] Smithsonian Report, 1846, pp. 6, 7.

bution to the general intelligence of mankind, to institute scientific inquiry as to the natural history, geology, geography, ethnology, archæology, and scientific utilities of any new possessions it may acquire. These inquiries should be made coherently and without clashing on the part of the various Government interests involved.

During the present year investigations among the American Indians have been conducted by the Bureau of Ethnology, and several collaborators of the Institution have made natural-history explorations, the details of which are given in the paragraphs devoted to the National Museum.

PUBLICATIONS.

Secretary Henry said "It is chiefly by the publications of the Institution that its fame is to be spread through the world, and the monument most befitting the name of Smithson erected to his memory." From the beginning of the Institution a considerable portion of its annual income has been expended in publishing the Smithsonian Contributions to Knowledge and the Smithsonian Miscellaneous Collections. Through these series, supplemented by the Annual Reports printed at the direct expense of the Government, and the publications of the National Museum, the Bureau of Ethnology, and the American Historical Association, issued under the direction of the Institution, nearly all branches of human knowledge are represented in the works published during the last fifty years, which form a library of nearly 250 volumes, beside several hundred pamphlet reprints of the memoirs and articles contained in the serial volumes.

Contributions to Knowledge.—One new memoir of this series was published during the year, the result of investigations by Drs. Lummer and Pringsheim, of Charlottenburg, Germany, on the ratio of the specific heats at constant pressure and at constant volume of air, oxygen, carbon dioxide, and hydrogen. This research was aided by a grant from the Hodgkins fund of the Smithsonian Institution. After a period of notable advance the kinetic theory of gases seems to have fallen into temporary abeyance, possibly from a fundamentally imperfect understanding of their behavior. Progress in the knowledge of this fundamental nature of gases may reasonably be looked for from interpretative researches on their thermal capacity, and this paper may be considered as a step in this direction. Aside from its exceptional importance in thermodynamics, the heat ratio is of interest as affording a clue to the character of the molecule, and Drs. Lummer and Pringsheim, using a new method, appear to have for the first time reached coincident results on the incoercible gases examined.

The original edition of the Secretary's memoir on The Internal Work of the Wind, published in 1893, having become exhausted, some additional copies have been printed from the stereotype plates, in which a few minor changes have been made.

The Secretary now has in preparation for this series a review of his investigations in aerodynamics, and in particular of experiments in developing the principles and methods of mechanical flight.

Miscellaneous Collections.—In this series five works have been published since my last report. These are a Catalogue of Scientific and Technical Periodicals, by Dr. H. C. Bolton; Catalogue of Pacific Coast Earthquakes, by Prof. E. S. Holden; Review and Bibliography of Metallic Carbides, by Prof. J. A. Mathews; Bibliography of Metals of the Platinum Group, by Prof. J. L. Howe, and a report by Dr. D. H. Bergey on the results of experiments to determine whether impure atmosphere produces a detrimental influence upon the animal organism as shown in greater susceptibility to certain diseases.

There have been also reprinted from the stereotype plates new editions of the Smithsonian Meteorological, Geographical, and Physical Tables. A Supplement to the Bibliography of Chemistry, by Dr. H. C. Bolton, containing about 4,000 additional titles, is in hand, and about half of the volume had been printed at the close of the year.

Smithsonian reports.—The Annual Reports of the Institution for the year 1896 and 1897 had not been issued at the close of the fiscal year, although the volume for 1896 was in the Government bindery, and presswork was in progress on the report for 1897, their completion having been delayed by the imperative need of supplying documents required by Congress for the military departments by reason of the Spanish-American war.

National Museum publications.—In addition to the Museum volume of the Smithsonian report, two series of publications are issued directly by the Museum, the Proceedings and the Bulletin. Of the first series Volume XIX was completed in bound form, the separate papers having previously been issued as pamphlets, and seventeen papers comprising Volume XX were distributed in pamphlet form during the year. A pamphlet containing instructions for collecting scale insects was published as Part L of Bulletin 39, and a circular was issued relating to the collection and preservation of the bones and teeth of the Mastodon and Mammoth.

Bureau of Ethnology reports.—The seventeenth report of the Bureau of Ethnology, for the year ending June 30, 1896, was sent to the Public Printer on July 6, 1897, and proof reading was completed before June 30, 1898, but actual presswork has not begun. The eighteenth report is also in the printer's hands, but no progress has been made beyond the revision of some first proofs.

Astrophysical Observatory publications.—There has been prepared and is now ready for publication a full report on the results of the researches carried on in the Astrophysical Observatory since its establishment and this work will probably be printed in quarto form during the next fiscal year, the cost of the publication being charged to the appropriation for the Observatory under authority of Congress.

Historical reports.—The Report of the American Historical Association for the year 1896 has been issued in two volumes, the first volume containing 22 papers on various historical subjects, the second volume being an exhaustive essay on the proposed amendments of the Constitution of the United States during the first century of its existence by Dr. H. V. Ames.

The report for the year 1897 was sent to the printer early in June, 1898, and much of it was in type before the fiscal year closed. It contains 20 papers relating to American history, including some of timely interest on the Cuban question, the Spanish policy in Mississippi after the treaty of San Lorenzo, and an exhaustive bibliography of Alabama.

These reports are prepared by the association and transmitted to Congress by the Secretary of the Smithsonian Institution, in accordance with the act of incorporation of the association. The series began with the report for 1889, but until 1894 no extra copies of the reports were printed for the use of the Institution. The edition is so small that it permits of distribution only to the most important American and foreign historical societies in exchange for publications of like character.

LIBRARY.

The number of accessions to the library has been greater than at any time heretofore, the total entries of volumes, parts of volumes, pamphlets, and charts reaching 40,715, an increase of nearly 5,000 over the previous year. The greater part of this has been sent to the Library of Congress to be placed with the Smithsonian deposit.

The Museum library shows a greatly increased use over last year. The limited quarters assigned for library purposes in the Museum are so greatly crowded that it has become necessary to provide additional book room, for which purpose a gallery directly adjoining the library has been erected and fitted with shelves, where space is provided for 18,000 volumes. This is rendered necessary by the purchase for the Museum, by Congressional appropriation, of the scientific library of the late Dr. G. Brown Goode. The Institution is especially fortunate in being able to obtain this library and the Museum now has the benefit of possessing the collections of books both of Professor Baird and Dr. Goode.

The relations between the Institution and the Library of Congress have been friendly and intimate, as in the past. The entire library has been transferred to the new building, and the small East stack, together with the large room adjoining it on the main library floor, have been assigned for the use of the Smithsonian deposit. Thus far, in the main, only publications of learned societies have been placed in this stack, whose supposed capacity is about 175,000 volumes. It is known that the titles of the Smithsonian publications number something like 350,000, but it has not been known until lately how many volumes were represented. The classification, which is now going on, and the rescue of the volumes from the condition in which they were put together, rather than assimilated or arranged, in the old crowded quarters, has enabled an approximate estimate to be made on this point. To what extent the Institution's collections have suffered from the crowded condition which has been too publicly known, that I should have any hesitation in thus referring to it, can not be definitely stated. It is believed that about 100,000 volumes or their equivalent are all that can be contributed to this stack.

The accumulations of the Smithsonian deposit for the last ten years, which had been unsorted in the old library, have been brought fairly under control, though much remains to be done before these will be in a satisfactory condition. The present wise organization of the Library of Congress into departments has yet one omission to which I feel compelled to call attention as it affects the interests of the Institution. No special provision was made for the care of the Smithsonian deposit. Naturally enough in the immense labor which has fallen upon the Library of Congress, the more pressing needs of the other departments have been first considered, but I have full confidence that this will soon be fully attended to.

The never-ending work of writing for exchanges and for the completion of incomplete sets, to which I have frequently referred, continues. The time will come when all resources of exchange will fail and when the deficiences in the important sets can only be provided by appropriation from Congress. While I have had this matter in mind for several years, I have been reluctant to bring it up for discussion at all until the Library of Congress was in condition for an intelligent treatment of the subject.

It will be seen from the library activities, a few of which I have enumerated, that in spite of the endeavor made by Secretary Henry to relieve the Institution of all expense of library work in arranging for the deposit of the Smithsonian library at the Library of Congress, by degrees a certain amount of such work and with it a very considerable attendant expense has grown up. This I trust will always be kept at a minimum, and the strength of the Institution, both through its library work and exchange service, employed for the increase of the Library of Congress and the Smithsonian deposit at that Library. It is nevertheless quite plain that no scientific establishment can exist and perform its functions without at least a considerable working library.

CORRESPONDENCE.

The present system of recording correspondence, which was fully described in my report for 1890, has proved of great convenience in handling the constantly increasing number of letters received from correspondents in all parts of the world. Numerous letters continue to be received seeking information on scientific and technical questions as well as on political, economic, historical, and other matters, and, while it has always been the policy of the Institution to give courteous attention to all such inquiries, it has become impossible to reply in detail to many of them; the writers, however, are referred to sources of information. The Institution has, unfortunately, perhaps, come to be considered a bureau of general as well as of scientific knowledge.

The following rule governing correspondence, adopted by the Regents in 1855, is still in force.

Resolved, That all correspondence of this Institution with any person or society shall be conducted by the Secretary, and no assistant or employee shall write or receive any official letter or communication pertaining to the affairs of the Institution except under the authority and by the direction of the Secretary; and all such correspondence shall be duly registered and recorded in such manner as the Secretary shall direct.

As interpreted, this resolution is entirely consistent with the free activities of the Institution and its bureaus in correspondence, the requisite authority being always understood to be given and exercised by the person to whom the Secretary delegates it in each instance.

INTERNATIONAL CONGRESSES.

The Eleventh International Congress of Orientalists was held at Paris from September 5 to September 12, 1897. There were thirty-four members registered from the United States, several of whom were present and took an active part in the proceedings. Dr. Paul Haupt, honorary curator of the division of historic archæology in the United States National Museum and professor of the Semitic languages in the Johns Hopkins University, Baltimore, represented the Smithsonian Institution. There were also delegates from the American Oriental Society, the American Philosophical Society, the University Archæological Association of Philadelphia, etc.

The Congress was organized in seven sections: I, Aryan; II, The far East (including China, Japan, Indo-China, the Indian Archipelago, etc.); III, Mohammedan; IV, Semitic; V, Egypt and Africa; VI, Archaic Greece and the Orient; VII, Ethnography and Folklore. Several of these sections were divided into two or three subsections.

Professor Erman, of Berlin, submitted the plan for a comprehensive *Thesaurus Verborum Aegyptiacorum*, which is to be published under the auspices of the royal academies of Berlin, Gottingen, Leipzig, and Munich; it will contain all the words found in hieroglyphic and hieratic texts. The card catalogue for the work will be finished in 1904, and the final redaction in 1908, while the printed edition will be completed in 1913. The assistance of Egyptologists all over the world is solicited for this gigantic undertaking.

Professor Goldziher, of Budapest, presented a report on the great Mohammedan Encyclopedia which is to be published under his editorial direction, and Professor Haupt announced a complete bibliography of Assyriology up to 1900, which is being prepared by Dr. Cyrus Adler, of the Smithsonian Institution.

The Secretary was in July, 1897, appointed delegate of the United States to the Seventh International Geological Congress, at St. Petersburg, Russia, during the first week of September. Other delegates from this country were Prof. George P. Merrill, of the National Museum, Rollin D. Salisbury, of New Jersey, and Charles R. Keys, of Missouri, these names being announced by the Institution to the Secretary of State, by whom the appointments were directly certified.

The special subjects under consideration related to stratigraphic and petrographic classification and nomenclature and the rules regarding the introduction of new terms into stratigraphic nomenclature. The congress will always remain memorable on account of the number and extent of the excursions offered the visiting geologists and the hospitality with which they were everywhere greeted. The excursions before the congress were: (1) to the Urals and Western Siberia; (2) to Esthonia, and (3) to Finland, and, after the congress, to the Caucasus by any one of three routes; thence to Tiflis, Baku, and Batoum, with side trips to Ararat, Mount Elbrous, the Crimea, and other less important points. The registration for the congress was unusually large, numbering some 850 signatures, of whom upward of 600 were actually in attendance either at the meeting in St. Petersburg or on some of the excursions. The next congress is to be held in Paris in 1900.

The Secretary presented to the Department of State the names of Dr. C. W. Stiles and Prof. E. L. Mark, and they were appointed delegates to the Congress of Zoology to be held at Cambridge, England.

The Secretary and Dr. Cyrus Adler were in June, 1898, appointed as delegates of the United States to a conference to be held in England for further consideration of an international catalogue of scientific literature mentioned in the last report.

EXPOSITIONS.

In my report for 1897 I made a brief reference to the participation of the Smithsonian Institution and its dependencies in the Tennessee Centennial Exposition, which was opened on May 1, 1897. A description of the exhibits prepared for that occasion under the direction of the Institution will be published in the Museum volume of this report.

By direction of Congress the Smithsonian Institution and its various bureaus have prepared exhibits for the Trans-Mississippi and International Exposition at Omaha, which opened on June 1, 1898. The sum of $19,491.71 was allotted to the Institution out of a general appropriation of $137,500 for the special exhibits of all the Executive Departments of the Government. A further allusion to this exposition will be found in the Appendix, and a full statement will be published in the report for 1899.

The Government of Norway invited this Government to participate in an international fisheries exposition, to be held at the city of Bergen, Norway, from May to September, 1898, and a resolution accepting this invitation and authorizing the Commissioner of Fish and Fisheries to arrange for a suitable exhibit was introduced into Congress. This resolution contained a phrase which authorized the Commissioner to employ the collections of the National Museum, at his discretion, for the purposes of this exhibit, and while the Institution has always been willing to aid any international exposition, a precedent might have been established which would seriously embarrass the Museum and lead to the temporary dismemberment of its collections. I accordingly took steps to have the wording of the bill so changed that the Commissioner of Fish and Fisheries might, "with the consent of the Secretary of the Smithsonian Institution, use any portion of the fisheries collection in the National Museum at said exposition," and this was readily agreed to by Congress, and enabled the Institution to be of service to the Fish Commission in making a proper exhibit without establishing a precedent dangerous to the Institution.

AMERICAN HISTORICAL ASSOCIATION.

Under the act of incorporation of the American Historical Association, approved January 4, 1889, the association reports annually to the Secretary of the Smithsonian Institution concerning its proceedings and the condition of historical study in America, and the Secretary is directed to "communicate to Congress the whole of such reports, or such portions thereof as he shall see fit." Nine volumes of these reports have so far been printed, and the report for the year 1897 is now in press. The reports from 1889 to 1893 were not at the disposal of the Institution, but beginning with the 1894 report a small edition has been available, which is distributed to State historical societies and some foreign institutions, the publications received in return being placed with the Smithsonian deposit at the Library of Congress.

MISCELLANEOUS.

Documentary history of the Institution.—In 1879 there was published a history of the origin and progress of the Smithsonian Institution from its establishment to the year 1877, including a full account of legislative proceedings from the Twenty-fourth to the Forty-fourth Congress wherein the Institution itself or any of its bureaus were concerned. There has now been prepared a similar history of the period from 1876 to 1896, which it is proposed to publish shortly.

Gifts and bequests.—Among the collections received by the Institution during the year and deposited in the National Museum may be mentioned a very interesting series of carbides and borides, presented by M. Henri Moissan, the products of his investigations with the electric furnace, and a large collection of archæological objects pertaining to the District of Columbia, bequeathed to the Institution by the late Mr. W. Hallett Phillips.

An ancient bronze ewer was received as a gift from Chang Yen Hoon, special ambassador from China to the United States.

Stereotype plates.—In the basement of the Institution building are stored the stereotype plates of most of the Smithsonian publications. These plates and engravers' blocks of illustrations are cheerfully placed at the disposal of publishers for supplementing or illustrating scientific works privately issued. The series of Miscellaneous Collections and Contributions to Knowledge are no longer stereotyped, but the regular edition has been increased, and in the case of works that are likely to be in more than ordinary demand extra copies are printed.

Smithson tablet.—A duplicate of the Smithson tablet was sent to Pembroke College, Oxford, the college from which Smithson was graduated. The two tablets sent to Genoa have been set in position, one of them at Smithson's tomb and the other in the English Church. During the last few years I have succeeded in getting some new information concerning the personal history of Mr. Smithson, and I have recently secured for the archives of the Institution a photographic copy of his will.

Tropical botanical laboratory.—The botanists of the United States in 1897 determined to establish a botanical laboratory in the American tropics, and a commission having been appointed to select a suitable site, the Institution extended all possible courtesies to the commission by presenting the plans of the project to the Department of State, through which necessary international arrangements were made to insure proper reception of the commission by the Governments of Mexico, Central America, and the West Indies. The commission consisted of Prof. Douglas Campbell, of Leland Stanford University; Prof. J. M. Coulton, of the University of Chicago; Prof. W. G. Farlow, of Harvard University, and Prof. D. T. MacDougall, of the University of Minnesota.

NATIONAL MUSEUM.

The temporary appointment of Mr. Charles D. Walcott as acting assistant secretary of the Smithsonian Institution in charge of the National Museum, following the death of Dr. Goode, was ratified by the Board of Regents on January 27, 1897. Mr. Walcott has continued to act in this capacity through the fiscal year covered by this report, and I take special pleasure in repeating my acknowledgment of the value and efficiency of the services rendered by him. With a corresponding regret I am obliged to announce that, owing to his exacting duties as director of the United States Geological Survey, he has found it necessary to terminate his official charge of the Museum with the close of the fiscal year 1897–98, thus closing a relationship equally satisfactory on its official and on its personal side. The Museum will continue to have the benefit of his association with it as honorary curator of the division of stratigraphic paleontology.

The Regents are aware that the Secretary, with Mr. Walcott's aid, arranged a modification in the administration of the Museum, intended to make it less dependent on the Secretary's immediate oversight of details. This consisted in gathering the different departments under three heads and placing three scientific men, who were believed to have shown a capacity as administrative officers, in their charge as head curators. The arrangement has worked well, but it should be given a longer trial before deciding that it is a suitable plan for the permanent administration of the Museum.

Under the present method the Secretary will not be required to give so much of his time to details of Museum administration as would have been demanded under the old system in the absence of a single head, and this result he is largely able to accomplish through the aid of the Assistant Secretary, who, without being designated to the exclusive charge of the Museum, will make its oversight a portion of his duties, in which he will be assisted by the head curators.

For the preservation and increase of the collections Congress appropriated $160,000 for the fiscal year now ended. From this appropriation are paid all expenses incident to the preservation, exhibition, and increase of the collections, except such as are referred to below. It covers the compensation of the scientific and clerical staff, and of the preparators, watchmen, and laborers; the cost of supplies required in the conduct of the Museum, such as preservatives, stationery, and other incidentals; the cost of transportation, the acquisition of specimens, etc.

This sum still left me unable to provide for additional permanent curators for the care of collections now without adequate supervision, and, for what is even a more urgent necessity, the means to pay for proper administrative aid in carrying on the Museum's work. Most of the scientific assistants are required to give much of their time to the performance of administrative duties in connection with the collections. A large number of divisions, moreover, are dependent for their administration entirely upon honorary officers, whose services have in the past been cheerfully rendered; yet the fact that their primary obligations are to other departments or bureaus of the Government has made it impossible for them to give such attention to their work in the Museum as the interest of the service really demanded, and has also prevented the secretary from calling upon them in such a way as he might were they paid officers of the Museum. Thus, while most fully recognizing the value of the services which these gentlemen have rendered, and the generous spirit in which they have been given, it yet does not seem possible to permanently administer so large an interest with the assistance of persons whose time can not be controlled by the chief officer in charge.

I repeat, to make my meaning quite clear, that the most urgent need of the Museum is the provision of an adequate fund for the administrative work, both in the handling of affairs and in the arranging of collections.

The appropriation for cases and other fixtures was $30,000 and for heating and lighting the Museum building $14,000. The purchase of books required for the technical library and the use of visitors in the exhibition halls, which has up to the present time been made from the appropriation for the preservation of collections, will hereafter be provided for specifically by a separate item, under which Congress has allotted the sum of $2,000 for the ensuing year.

The sum of $4,000 was allowed for repairs to buildings, shops, and sheds, and an item of $2,500 for the removal and rebuilding of the two sheds adjacent to the south side of the Smithsonian building. The latter, which have been a source of menace to the main building, were torn down and reconstructed in other and more suitable locations.

The Museum building not being provided with a basement, it has been necessary to rent temporary quarters elsewhere for workshops and for the storage of surplus specimens, and the furniture used for exposition purposes. These structures are not fireproof, and in the interest of the safety of the Government property I therefore included in my estimates for 1898–99 an item of $50,000 for the construction of a suitable building, 50 feet by 150 feet, and provided with a basement, which should take the place of the various buildings and sheds already alluded to. I suggested a site between the National Museum and the Army Medical Museum buildings. I regret to say that this item was not allowed, but in place thereof the amount appropriated for renting purposes was increased from $2,000 (allowed for 1897–98) to $4,500 for the year 1898–99. This will enable me to secure additional quarters for immediate needs.

In 1897 and again in 1898 Congress appropriated $8,000 for erecting galleries in the Museum building. This amount was sufficient for the erection of seven galleries. An additional allowance of $10,000 has also been granted by Congress for furnishing railings, painting the galleries, connecting them with those in adjoining hall, placing a skylight in each court, and providing a ventilator in one of the ranges.

I am pleased to report that the full amount asked for printing and binding ($17,000) has been allotted, which will enable me to push forward the publication of several important manuscripts, the printing of which has long been withheld for lack of funds.

The expenditure of a sum not exceeding $5,500 from the "Preservation of collections" appropriation was authorized for the preparation of drawings for the illustration of Museum publications.

For the purchase of the private library of the late Dr. Goode the sum of $5,000 was appropriated by Congress. This library is a very valuable one, formed with rare discrimination and intelligence, and comprising the best treatises, chiefly on natural history and methods of museum administration. It comprises 2,900 volumes, 18,000 pamphlets, and 1,800 portraits, autographs, and engravings.

The total number of lots of specimens received during the year was 1,441, some of these containing several hundred each. These accessions include more than 450,000 objects, and I would call special attention to this extraordinary increase, perhaps the largest during the last fifteen years. This fact seems to establish in a marked degree the popularity of the Museum and the general desire on the part of the public to aid in building up its collections. The conditions existing during the year have been peculiarly unfavorable for making special effort to increase the collections, and this large addition to them must be regarded as the result of a very earnest desire of persons interested in the Museum to assist in promoting its objects. The number of specimens now recorded in all the departments of the Museum is considerably more than four millions.

The Museum has continued its practice of carrying on exchanges of specimens with museums and individuals in foreign countries. Among the most important ones initiated or completed during the year 1898 may be mentioned those with the Imperial Royal Natural History Museum, of Vienna; the Paleontological Museum of the Royal Academy, Munich, Bavaria; the Natural History Society of New Brunswick, St. John; the Branicki Museum, Warsaw, Russia; the Zoological Museum of the Imperial Academy of Sciences, St. Petersburg; the Royal Museum of Natural History, Stockholm, Sweden, and the Museum of Natural History, Geneva, Switzerland.

A more detailed reference to these transactions may be found in the Appendix.

BUREAU OF AMERICAN ETHNOLOGY.

Researches relating to the American Indians, conducted under the Smithsonian Institution in accordance with the act of Congress, have been continued by Maj. J. W. Powell, the Director of the Bureau, assisted by Mr. W J McGee, Mr. F. W. Hodge, and other scientific collaborators, whose respective services will be found more fully detailed in the director's report. The field operations have been extended into a large number of States and Territories; and also incidentally into districts of neighboring countries occupied by tribes affiliated with the aborigines of the region now comprised in the United States. In the office studies have been carried on of the field material, with a view to defining those characteristics of primitive culture affecting relations among the tribes.

The work of exploration has been conducted in several parts of the United States. An examination was made into the shell mounds on the coast of Maine, resulting, in the opinion of the director, in the identification of the Mound Builders with the tribes found on that coast at the settlement of the country. From excavations in Mexico and Arizona a large collection of interesting objects were obtained and much archæological and ethnological data acquired. The difficult ascent of the summit of the Mesa Encantada, near Acoma, was accomplished, and from relics found there the essential features of the Acoma tradition have been substantiated. Explorations were also extended across the frontier into Mexico, resulting in the acquirement of information tending to throw much light on the little-known customs of the border tribes. The objects collected during these various explorations have been placed in the National Museum and the new information acquired has been added to the archives of the Bureau and incorporated in memoirs now in preparation or completed for publication.

The study and arrangement of the collections of aboriginal handiwork obtained in Florida has been continued and progress made in the preparation of a report on the prehistoric key dwellers on the eastern shore of the Gulf of Mexico.

The study of decorations and researches into their symbolic uses have been continued.

Interesting observations on the development of institutions among the Papago and other American tribes and satisfactory progress in the researches in linguistics, particularly in the preparation of a comparative vocabulary of Algonquian dialects, as well as in studies of the Iroquoian languages, the dialects of the Mescalero and Jicarilla Apaches, and of the Cherokee myths, have been made. Researches in Indian sign language have been resumed. The director has continued the development of a system of classification designed to indicate the place of the the American Indians among the peoples of the earth.

Satisfactory progress has been made in the revision of the proofs of the seventeenth and eighteenth annual reports and in editorial work on the manuscript of the nineteenth annual report. The demand for these reports in advance of their publication is great, while the supply of those of previous years is practically exhausted.

Further details concerning the operations of the Bureau may be found in Director Powell's report, forming Appendix II.

INTERNATIONAL EXCHANGES.

I need hardly repeat what I have already said in previous reports—that the growth of the operations of the exchange service testifies to its good management and general acceptability, even with the disadvantages under which its labors are carried on. In 1887 it sent out 71 tons of documents and had 2,165 correspondents in this country and 7,396 correspondents abroad; during the past year it transmitted 151 tons and had 6,915 correspondents at home and 22,543 abroad. There is no part of the Smithsonian Institution which more efficiently carries out the large purpose of its founder, to diffuse knowledge among men, and it is through this, as much as through any other branch, that its name is known throughout the world.

Fifty years ago, when this work was first commenced, entirely at the charge of the Institution, an arrangement was made through the generosity of certain steamship lines by which transport could be had gratuitously. This arrangement has been, to a great extent, necessarily continued, and, although conditions have entirely changed, the Institution is still compelled to carry matters of international interest and importance by slow steamers because where the service is gratuitously given no choice can be exercised. It is a mistaken economy to think it for the advantage of the Government, which now spends so many thousands of dollars on this work, to yet fail to meet the vital conditions of business success—reasonable dispatch—because it would involve the expenditure of some $3,000 additional annually.

At the present time it is unhappily true that different bureaus of the Government which have the right to make use of this method prefer to spend more money and to send their publications at their own cost and trouble, usually through the mails, only because they can deliver them more promptly than those who would gladly make it a special boast that they were the promptest and most expeditious, as well as the cheapest, of Government dispatches.

Where ocean freight is charged it is computed by the cubic foot, and the average rate that is demanded by the fast steamers from New York to European ports may be placed at 20 cents; but while the above estimate is made upon the calculation that all shipments could be made at the ton-measurement rate, quite two-thirds of them would measure under a ton, and would come under the rate of what is known as "minimum bill of lading charge," which is never less than $5 for each shipment. This makes a total of about $2,000 from Washington to various ports of debarkation throughout the world; and this, be it distinctly observed, is without ordinarily using the express either from Washington to the port of shipment on this side or from the foreign port of destination to the final address on the other.

It would doubtless be somewhat quicker if the express were used, but the gain between Washington and New York in time would be less than a day, and the cost on this part of the transit would be multiplied nearly fourfold, so that if I look at the matter as though the interests of an ordinary business were in question I do not feel that the expenditure under these conditions for an express freight between Washington and New York would be justified; and since it is as a business investment that I am asking Congress to consider this small appropriation, I do not advise that it shall include the cost of the land express to be used as an ordinary means.

It is to be understood, then, that under this estimate land transportation is still supposed to be, as a rule, by freight trains, both in this country and in Europe. As the Institution has little to do with forwarding exchanges from European ports to their ultimate destinations, it is impossible to state definitely what the cost would be of improvements which would bring in all desirable expedition to this part of the service, and it is not included here. It is, however, necessary that a reasonable provision for the special transmission by express of belated packages from Washington to New York and for the payment of postage on a certain limited number, mostly small and far remote destinations, which can be forwarded more advantageously by the mail, with some minor but needed matters, should be made, and this will add not over $1,000, making the $3,000 estimated for.

With a view to improving the service and establishing more intimate relations with the correspondents of the Institution, who have so generously cooperated in its advancement, the chief clerk was instructed to personally visit, in the autumn of 1897, the exchange agencies at Brussels, Leipzig, Vienna, Budapest, Paris, and London. The work accomplished was highly satisfactory, and resulted not only in making many useful changes, but also in bringing about a closer relationship, especially with those bureaus abroad which are conducted and supported by Government.

The exchange territory represented for many years by the agent of the Institution at Leipzig has included not only Germany, but Austria-Hungary and the Balkan countries as well. The constantly increasing demands upon this agency has made it necessary to readjust its functions, and as a consequence new agents have been appointed at Vienna and Budapest. While the necessary additional expenditure on account of the new agencies will be considerable, the advantage to the service will more than compensate for the increase.

The service provides for the forwarding of United States official publications to distributing centers abroad and for their systematic delivery to specific addresses; for transmitting the reports and memoirs of institutions and individuals of this country to their correspondents in other parts of the world, and for the transmission to and delivery in the United States of similar publications in exchange, even from remote parts of civilization.

For defraying the expense of this service during the past year there were available resources aggregating $25,193.53, of which amount $19,000 were appropriated by Congress and $6,193.53 were derived from repayments at the rate of 5 cents per pound on the exchanges of Government bureaus and State institutions, this being a partial reimbursement of the expense incurred for packing, transportation, and clerical work.

In my last report I stated that exchange relations were suspended with Turkey, Greece, and Cuba, and I regret to say that even now the Institution is awaiting the consummation of arrangements with the first two countries named. An agency had been established in Havana just prior to the blockading of that port by the United States fleet, and it will doubtless be reestablished at an early date. Owing to restrictions placed upon all intercourse with Spain and her colonies during the recent war, no exchanges have of late been forwarded by either country.

Comparison with the report for the year ending June 30, 1897, shows a marked increase in the number of correspondents and the amount of publications transmitted. The number of correspondents now aggregates 29,458, and the weight of transmissions during the year exceeded 150 tons, distributed among 93 countries.

Since my last report a revised edition of the International Exchange List has been published, containing the names of 9,414 institutions in other countries which are in communication with institutions in the United States through the Smithsonian Institution. The last edition was published in 1885. Appended to this report is a map of the world showing the distribution of the correspondents of the exchange service.

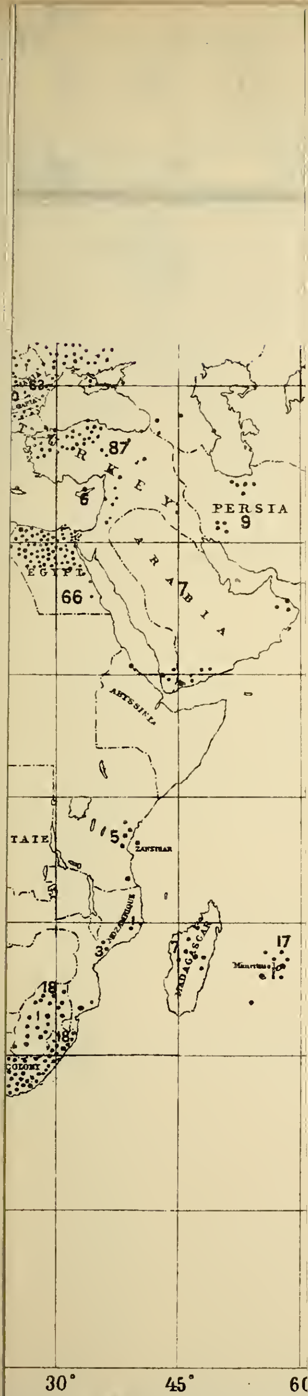
THE NATIONAL ZOOLOGICAL PARK.

For the fiscal year ending June 30, 1898, the following appropriation was made for the National Zoological Park by the sundry civil act approved June 4, 1897:

National Zoological Park: For continuing the construction of roads, walks, bridges, water supply, sewerage and drainage; and for grading, planting, and otherwise improving the grounds; erecting and repairing buildings and inclosures; care, subsistence, purchase, and transportation of animals, including salaries or compensation of all necessary employees and general incidental expenses not otherwise provided for, fifty-five thousand dollars; one-half of which sum shall be paid from the revenues of the District of Columbia and the other half from the Treasury of the United States; and of the sum hereby appropriated five thousand dollars shall be used for continuing the entrance into the Zoological Park from Woodley lane and opening driveway into Zoological Park, from said entrance along the bank of Rock Creek.

The sum thus appropriated was less by $10,000 than that for the preceding fiscal year. This has necessarily occasioned some embarrassment in the administration, and retarded development, especially in the construction of buildings. It will be remembered that no grant has ever been provided for any permanent structure for animals in the park, other than the small "animal house," so called, and the log cabin where the elks are sheltered, so that nearly all of the animals are after eight years still sheltered in the temporary sheds run up to receive them at the time of the first appropriation. It had been hoped that something would have been done this year, but it has not been possible to erect the constructions mentioned in the last annual report as desirable.

Through the courtesy of the Commissioner of Fish and Fisheries the park was able to secure the tanks and other apparatus used for the exhibition of fish and aquatic animals at Atlanta, Ga. These tanks have been temporarily installed in a shed formerly occupied as a workshop and constitute the nucleus of an aquarium which it is hoped may become an attractive feature of the park. At present the exhibit com-



RNATIONAL EXCHANGE SERVI
S INDICATE THE RELATIVE

THE NORRIS PETERS CO. PHOTO-LITHO., WASHINGTON, D.C.

MAP SHOWING DISTRIBUTION OF CORRESPONDENTS OF THE SMITHSONIAN INTERNATIONAL EXCHANGE SERVICE. THE NUMERALS REPRESENT THE ACTUAL NUMBER IN EACH COUNTRY, AND THE DOTS INDICATE THE RELATIVE DENSITY.

prises only fresh water species, but a series of tanks for sea water will also be established. No part of the park attracts more attention or interest than this, and I could wish that Congress would provide the means for making a better exhibit. This is only one out of many instances, however, of the need of buildings. The temporary sheds already alluded to were put up at first in that form at the instance of the Appropriation Committee, which desired to await the result of experience before erecting permanent quarters. These sheds are rotting and all but ready to fall, and some appropriation for buildings must be made.

The births in the collection continue to be more frequent than was anticipated. As wild animals do not ordinarily breed in captivity, this increase is gratifying as bearing testimony to the care which has been bestowed by their keepers to preserve them in proper conditions of health and activity.

The roads of the park have received the usual attention during the year. The appropriation bill provided for the continuation of the Rock Creek drive along the creek. This work has been done, the amount appropriated being sufficient to construct an excellent road from the new bridge built last year to the bridge near the Quarry road entrance. As funds become available this driveway will be continued toward the upper end of the park. The completion of the portion of this roadway connecting with Woodley road has been deferred for the present on account of the probable addition of land to the area of the park in that vicinity. A bill has been presented to Congress providing for such addition, and the road can be much more advantageously constructed should this increase of the park reserve be provided.

It is hoped that the probable extension of the jurisdiction of the United States over foreign territory may lead to increased collections for the park. There are many animals and birds in Cuba, Porto Rico, and the Philippines which are not represented here. It seems highly desirable that the fauna of these regions should be more widely known, and it is therefore intended, if funds are provided for the purpose, to make a special exhibit of specimens collected in these countries. In order to do this a new building especially constructed for tropical birds is indispensable.

The collection has suffered somewhat during the year from the casualties that are a necessary consequence of keeping wild animals in confinement. The "cattle and game disease," an epidemic disorder that has proved very fatal in European collections, appeared suddenly and carried off several animals. Its progress was soon arrested by promptly disinfecting the pens, isolating the sick, and removing the unaffected animals to other paddocks.

Several measures were introduced into Congress during the last session which had for their object the readjustment of the boundary of the park. Since the establishment of a permanent plan for the roadways of the District of Columbia it has been made evident that the existing boundaries are not in all respects satisfactory, as they do not always coincide with the regular highways, and therefore permit of buildings being placed in close proximity to the park, a condition obviously unsuitable both for the seclusion of the animals and because of the probability of disorderly conditions arising upon such properties.

The most notable of the efforts made to secure a better arrangement was the bill on the subject introduced by Senator Gallinger, which was favorably reported by the Committee on the District of Columbia of the Senate, finally passed by the Senate on July 7, 1898, and is now before the Committee on Public Buildings and Grounds of the House of Representatives.

The text of the bill as it passed the Senate is as follows:

S. 4191.

AN ACT To readjust the boundary of the National Zoological Park and preserve its seclusion between Park road on the east and Cincinnati street and Connecticut avenue on the west.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That a commission, to consist of the secretary of the Smithsonian Institution, the president of the Board of Commissioners of the District of Columbia, and the Engineer Commissioner of said board, is hereby authorized and empowered to acquire, by purchase or condemnation, in the same manner as was adopted for the acquirement of property already embraced in the National Zoological Park under the provision of the Act of March second, eighteen hundred and eighty-nine, the tract of land lying south of the National Zoological Park owned by the Union Benevolent Association of the District of Columbia (colored) and now occupied as a cemetery, and such parcels of ground adjoining the said park and between its present boundaries and Connecticut avenue extended on the west and the nearest road shown on the recorded highway extension plans of the first section on the east and south (inclusive of such road in case the same is not yet dedicated to public use) as they shall deem necessary for preserving its safety and perpetuating its seclusion; these properties, along with Joliet street, already purchased, to be made a part of the said park, for which purpose the sum of twenty-five thousand dollars is hereby appropriated, to be paid half out of the District funds and half out of the United States funds. The Union Benevolent Association of the District of Columbia (colored) is hereby authorized to sell and convey any portion or all of the tract of land owned by them on the southern side of the Zoological Park now occupied as a cemetery.

It would seem that the passage of this bill is very desirable, and I take occasion to refer in this connection to the letter which I quoted from an eminent landscape artist, Mr. Olmsted, in my report for the fiscal year ending June 30, 1895.

ASTROPHYSICAL OBSERVATORY.

The work of the past year has been successful beyond expectation, and, as is stated in the report of the Aid acting in charge, it has resulted in the discovery and determination of position of over 500 new absorption lines, so that we have now over 700 new lines of well-determined positions, and we may be said now to know, by the aid of the bolometer and the labors of the observatory, more lines in this invisible spectrum than were known in the visible one up to the great research of Kirchoff and Bunsen, which opened the era of modern spectrum analysis. Moreover, these lines, the exactness of whose determination has now reached a surprising degree of perfection through the recent improvements in the delicacy as well as the precision of both bolometer and galvanometer, and through other improvements in the apparatus (improvements due principally to the present Aid acting in charge), depend not only on the instruments, but on the labors of those who have used them, the comparator measurements alone having included, as stated in the body of the report, about 44,000 separate observations.

A great deal of other work has been done at the observatory, but nothing which in importance and present and prospective interest compares with this main research in the infra-red spectrum, which is now known throughout nearly the whole of the invisible portion of the solar energy, and extends through a range of wave lengths considerably over twelve times that known to Sir Isaac Newton, the present exact knowledge of this region being due not exclusively, but it may properly be said principally, to the labors of this observatory.

I call attention in this connection to the interesting remarks made in the report to the effect that very marked changes of absorption have been observed at various parts of the infra-red spectrum. In one part of the invisible region a decrease in absorption, amounting to nearly half the total, took place in February, and this abnormal state continued until May, when the usual condition gradually returned. As this change is found to occur yearly at about the same period, the idea presents itself that the growth of vegetation, so rapid in these months, may abstract from the air large quantities of vapor active in absorption at this point in the spectrum, but this interesting possibility has not yet, it will be understood, been fully verified.

In this, however, and other discoveries of a similar nature we have the earnest of the fulfillment of long cherished hopes, already alluded to by me, for the ultimate benefit of these researches, not only to science, but to concerns of practical moment and even of national utility.

NECROLOGY.

Gardiner Greene Hubbard was born in Boston August 25, 1822, and died in Washington on December 11, 1897. After preparation in the Boston schools he entered Dartmouth College, being graduated bachelor of arts in 1841. He studied law in Cambridge, and was admitted to the bar of Boston, where he practiced his profession for twenty years, and later at the national capital.

His first interest in educational and scientific matters appears to have been connected with the improved education of the deaf, and he was the founder, in 1846, of the first school established in the United States for teaching the deaf to speak. He was for ten years a member of the State board of education of Massachusetts, and served as a commissioner for that State to the Centennial Exhibition at Philadelphia in 1876. He was also connected with the department of awards of the Atlanta Exposition, 1895, and the Nashville Exposition, 1897. In 1876 he was appointed by President Grant chairman of a special commission to investigate the question of railway mail transportation. He was a doctor of laws of his own college (Dartmouth), and of Columbian University, at Washington, of which he was also a trustee. During the last ten years of his life he evinced a very great interest in the scientific work at the national capital. He was president of the National Geographic Society, and labored unceasingly for the advancement and popularization of its work. He was president of the Joint Commission of the Scientific Societies of Washington, and was connected with a number of the hereditary and patriotic organizations. He was elected a regent February 27, 1895, and was made a member of the executive committee, and gave much time and thought to all his duties as regent. The Board of Regents unanimously adopted the following minute by a rising vote in recognition of his services to the Institution:

Whereas the Hon. Gardiner Greene Hubbard, a citizen regent and a member of the executive committee of the Smithsonian Institution, died at his residence in this city on the 11th day of December, 1897,

Resolved, That the Regents of the Institution place upon their records this testimonial of their respect and admiration for Mr. Hubbard as a singularly public-spirited citizen, an ever-generous promoter of education, and active patron of scientific work; and this expression of their sincere regret for the loss of a colleague and friend, whose life was adorned by so many personal virtues, and whose association with them has left so many endearing memories.

Resolved, That a copy of this minute be engrossed and transmitted to the family of Mr. Hubbard.

Miss Fannie R. Schaeffer, for more than twenty years an efficient clerk in the Institution, died September 18, 1897.

Respectfully submitted.

S. P. LANGLEY,

Secretary of the Smithsonian Institution.

APPENDIX TO SECRETARY'S REPORT.

APPENDIX I.

THE NATIONAL MUSEUM.

SIR: I have the honor to submit the report of the National Museum for the year ending June 30, 1898.

In response to your request that the report shall begin with the following statements—

1. The amount, kinds, and classes of property belonging to the Museum;
2. The amount of such property acquired during the twelve months covered by the report;
3. The extent and kind of improvements made in the building and grounds during the past year, and the estimated cost;
4. The extent and character of the losses of property, and the origin and causes,

I have the honor to report that the fixed property of the National Museum consists (in addition to its building, heating plant, and other equipments) of collections, cases and other receptacles, office furniture, and books.

The collections include objects in every branch of natural history, geology, and anthropology, and comprise more than 4,000,000 specimens.

The cases in the exhibition halls number about 2,000. Besides these, 130 cases contain exhibits at the Omaha Exposition, and 1,300 are in use in the workrooms and storage quarters.

The office furniture comprises about 900 pieces, such as tables, desks, chairs, file-cases, typewriters, and book-cases, besides minor articles. The Museum also owns 485 lecture-room chairs of an inferior quality that should be replaced at an early day.

The library contains about 11,000 volumes and about 7,500 pamphlets.

During the fiscal year covered by this statement the Museum acquired more than 450,000 specimens and 441 books, 797 pamphlets, and 4,929 parts of periodicals, and added to its permanent stock cases and other furniture and fixtures to the amount of $30,000, of which $15,000 was used for furnishing the new galleries provided by Congress.

During the year the sheds adjoining the Smithsonian building on the south side were torn down and reconstructed at a safe distance from the building. The work cost in round numbers, $2,000.

The galleries provided by Congress for the Museum building were erected during the year. These were three in number, and cost $8,000, the amount appropriated.

The losses of property during the year were of trifling extent, and were only such as naturally occur where very large numbers of receptacles, as cases, boxes, trays, bottles, etc., are in use. It should be remarked in this connection that all cases and other furniture and the like when worn out and no longer of use to the Museum, are regularly condemned and sold at auction, and the proceeds turned into the Treasury, as required by law.

In the following condensed statement the more important facts connected with the work of the National Museum during the fiscal year ending June 30, 1898, are presented:

The Museum staff.—A general reorganization of the scientific departments of the Museum went into effect July 1, 1897. Under this plan Mr. W. H. Holmes was made head curator of the newly organized department of anthropology, Dr. F. W. True head curator of the department of biology, and Dr. G. P. Merrill head curator of the department of geology.

Mr. W. H. Ashmead was appointed assistant curator of the division of insects on July 1, 1897. On November 12 Dr. W. L. Ralph was appointed honorary custodian of the section of birds' eggs, and Dr. H. G. Dyar was made honorary custodian of the section of lepidoptera. Mr. W. T. Swingle was appointed honorary custodian of the section of algæ, and Dr. D. G. Fairchild was appointed to a similar position in the section of lower fungi. Both of these appointments took effect December 7.

Mr. Gerrit S. Miller, jr., was given a temporary appointment as assistant curator of the division of mammals on February 15, 1898. On April 30, Dr. J. Walter Fewkes was appointed a collaborator in the division of ethnology.

Accessions.—The accessions of the year number 1,442. While this record shows a slight falling off when compared with that for the preceding year, it should be noted that many of the accessions embraced a large quantity of material, so that the total number of specimens acquired represents a very large increase over the acquisitions of recent years. Altogether, more than 450,000 specimens, as already stated, were added to the collections, raising the grand total on June 30, 1898, to above 4,000,000.

In calling your attention to the accessions of greatest importance, I will divide my remarks under the three headings, anthropology, biology, and geology—these being the designations of the three scientific departments of the Museum (under which all divisions and sections are embraced) in accordance with the revised scheme of classification now in effect.

Anthropology.—Considering first the department of anthropology, attention is called to a large collection of antiquities and ethnological material, embracing more than 12,000 specimens, bequeathed to the Smithsonian Institution by the late W. Hallett Phillips, by whom the material was largely collected. The specimens are accompanied by notes prepared by Mr. Phillips, and the collection, as a whole, is of exceptional value. It consists mainly of stone implements from the Potomac region, but includes also 106 ethnological specimens from Polynesia. From the Bureau of American Ethnology has been received a valuable series of ancient stone and earthenware utensils from graves and mounds in Arkansas, and a collection of antiquities from the mounds of the Etowah group of Georgia. The last-named collection, together with the material previously received from the same locality, constitutes an exceedingly valuable assemblage of archæological material. Through the courtesy of Surg. Gen. G. M. Sternberg, a series of over 2,000 human crania, mainly of the Indian tribes of North America, has been transferred to the National Museum from the Army Medical Museum. Dr. Roland Steiner, of Grovetown, Ga., deposited an extensive series of stone implements from various parts of Georgia, and M. Emile Granier, Paris, France, deposited a collection of ethnological material from the Indian tribes of the Great Plains and the Rocky Mountain region. Other loan collections worthy of note are a series of personal mementos of the late Gen. W. S. Hancock, deposited by G. R. Hancock, of the West Point Military Academy, a number of Jewish religious ceremonial objects, deposited by Mr. H. E. Benguiat, San Francisco, Cal., and a valuable collection of Japanese porcelains from Miss E. R. Scidmore.

Prof. Alexander Graham Bell deposited a large number of pieces of apparatus made and used by himself in his experiments and researches, including a series illustrating the invention and development of the Bell telephone. The General Electric Company deposited several dynamos and other pieces of apparatus of great historical value. The Coe Brass Manufacturing Company, of Ansonia, Conn., presented ten dynamos made between the years 1873 and 1879 by William Wallace. Some of these machines were in practical operation during the Centennial Exhibition at Philadelphia. An electric generator made in 1867 by Mr. Charles A. Seeley and an electric motor devised in 1834 by Thomas Davenport were received on deposit from the American Institute of Electrical Engineers. Altogether, the pieces of electrical apparatus received represent nearly the entire range of American invention, forming the basis of the practical methods of electric arc and incandescent lighting. Duplicates of few, if any, of these machines exist.

Biology.—Among the additions to the collections in the department of biology the largest and one of the most important is a collection of about 200,000 specimens of Coleoptera, presented by Messrs. H. G. Hubbard and E. A. Schwarz, of the Department of Agriculture. The addition of this material places the collection of insects in the National Museum ahead of all others as regards North American Coleoptera. Dr. W. L. Abbott has presented during the year large collections of birds, mammals, reptiles, and insects from Lower Siam and Kashmir. The material which Dr. Abbott has collected and donated to the National Museum during a period of several years past now constitutes the most valuable portion of the Old World collections in its custody. Valuable specimens of birds' eggs have been received from Dr. W. L. Ralph, of Utica, N. Y., another generous contributor to the national collections. Prof. Dean C. Worcester, of Ann Arbor, Mich., presented 600 bird skins, 900 eggs, and 250 nests, all from the Philippine Islands. Large additions to the collection of fresh-water mussels have been made through the cooperation of Dr. L. T. Chamberlain, of New York City. A collection of more than 86,000 specimens of land and fresh-water shells was presented by Dr. R. Ellsworth Call, of Cincinnati, Ohio. Mr. Outram Bangs, Boston, Mass., presented an interesting series of bird skins from Santa Marta, Colombia. Valuable accessions from the United States Fish Commission, the Biological Survey of the Department of Agriculture, and other Government bureaus, have been received. A collection of invertebrates obtained by the naturalists of the steamer *Albatross* in 1896 from the coasts of California, Japan, Kamchatka, and in the Bering Sea, and a quantity of material, comprising more than 600 lots, collected by the assistants of the Commission during the past thirteen years, deserve special notice. A number of valuable types and cotypes of fishes have also been transmitted by the commission. A large lot of land shells collected by the Biological Survey of the Department of Agriculture, was received during the year. This collection is regarded as the most intrinsically valuable acquisition of the year in the division of mollusks, comprising as it does an unusual number of undescribed species and others not before represented in the collection. A series of about 240 specimens of rodents from Patagonia was obtained by purchase.

Geology.—The department of geology has been enriched by the addition of a considerable quantity of important and interesting material. Through the bequest of the late I. H. Harris, of Waynesville, Ohio, a valuable collection, consisting of more than 20,000 specimens of fossils, has been received. This is one of the finest collections of fossils of the Cincinnati group in existence. It is particularly rich in starfishes, crinoids, and trilobites. Mr. R. D. Lacoe, Pittston, Pa., has added to his previous magnificent contributions by the donation of his collection of fossil insects, comprising over 4,600 specimens, of which more than 200 are types. Six hundred specimens of Kinderhook crinoids, corals, and mollusca were received from the United States Geological Survey. A large amount of vertebrate paleontological material, collected under the direction of Prof. O. C. Marsh during his connection with the United States Geological Survey, has been turned over to the Museum during the year. A valuable collection of Mosasaurs from the Cretaceous of western Kansas, two collections of Elasmobranch teeth and spines from the Carboniferous of Iowa, and an unusually fine skull and some bones of *Claosaurus* were obtained by purchase.

Specimens of many new minerals were received during the year and added to the collections. The division of physical and chemical geology has been enriched by the acquisition of a large cluster of basaltic columns from near Bonn, Prussia, some large masses of beautiful orbicular granite from Sweden, fulgurites on Andesite from Little Ararat in Armenia, and a large amount of petrographic material from the United States Geological Survey and other sources. The head curator of the department of geology collected some beautiful, clear masses of rock salt at Heilbronn, Prussia. Specimens of kaolin and clays from Germany and an excellent series of telluride ores from Cripple Creek, Colo., have also been received.

Foreign exchanges.—A few of the more important exchanges with foreign establishments and individuals are here referred to: From the Imperial Royal Natural History Museum, Vienna, Austria, 66 specimens of Tertiary corals were received in exchange for Lower Cretaceous fossils. The Paleontological Museum of the Royal Academy, Munich, Bavaria, received from the United States National Museum 16 specimens of Cambrian fossils in exchange for material sent some time ago. Thirty-three specimens of fossil plants, representing 20 species, were received from the Natural History Society of New Brunswick, St. John, and 90 specimens of fossil plants have been sent in return. The Branicki Museum, Warsaw, Russia, has received 170 bird skins from the National Museum, in continuation of exchanges. Land shells from Transcaspia and the Caucasus and marine shells from the coast of Russia have been received from the Zoological Museum of the Imperial Academy of Sciences, St. Petersburg, in exchange for about 2,000 specimens of shells from the National Museum. Mons. M. Cossman, Paris, France, sent a collection of shells in exchange for publications. Sixty-two specimens of Actinians have been transmitted to the Royal Museum of Natural History, Stockholm, Sweden, in exchange for material yet to be received. Crustaceans have been sent to the Museum of Natural History, Geneva, Switzerland, in return for specimens already received and in continuation of further exchanges.

Distribution of specimens.—There were sent out as gifts or in exchange during the year about 32,000 specimens, a considerable increase compared with the number for the preceding year. About one-half of the distributions consisted of marine invertebrates, a large number of these specimens having been prepared and transmitted to schools and colleges throughout the country. Nearly 7,500 specimens were lent to specialists for study.

Specimens received for determination.—There has been a decrease in the number of specimens received for determination, the total having been 576 lots, or 140 lots less than for the preceding year. Since very little material of value is acquired in this way, this decrease is not to be regretted, although the work of identification is not unwillingly undertaken, since it has long been the policy of the Museum to render such assistance to collectors and others as may be practicable.

Explorations.—Material of great scientific value has been received as the result of explorations conducted by the Bureau of American Ethnology. About 1,300 specimens of pottery and other relics from Arizona have been added to the collections through the efforts of Dr. J. Walker Fewkes, who has been particularly successful in his archæological explorations in the southwest during the past few years. A number of unique ethnological specimens from Patagonia were received from Mr. J. B. Hatcher. Explorations undertaken by Mr. Gerard Fowke, of the Bureau of Ethnology, in Brown County, Ohio, yielded a small collection of Mound Builders' relics.

Mr. R. P. Currie, of the National Museum, visited Liberia with Prof. O. F. Cook, for the purpose of collecting natural history material, and succeeded in gathering a large number of insects, spiders, and myriapods. Valuable specimens of mammals, birds, and reptiles were also secured. A number of rare birds from the vicinity of Lake Okechobee, Florida, were collected by Mr. Robert Ridgway. Interesting specimens of fishes and mollusks were obtained by Mr. Charles Schuchert near Disko Island, Greenland. Some very rare insects from the Commander Islands were secured by Dr. Leonhard Stejneger while serving as a member of the Fur-seal Investigation Commission. Mr. J. N. Rose visited Mexico during the summer of 1897, and spent about four months in making collections of botanical material. A large number of valuable specimens were obtained, including representations of more than 100 species new to science.

A large number of plants from the Cretaceous and Tertiary formations of northern Greenland were obtained by Messrs. David White and Charles Schuchert. Mr.

Schuchert also made collecting trips to Missouri and northern New York. Dr. George P. Merrill brought home some interesting geological material collected during his visit to Russia in 1897.

Visitors.—During the year 177,254 persons visited the Museum building and 99,273 were admitted to the Smithsonian building, making a total of 276,527.

Publications.—The Annual Report of the National Museum for 1895 has been published, the Report for 1896 was nearly all in type at the close of the fiscal year, and the proof reading of the administrative portion of the volume for 1897 has been finished. The papers in the appendix of the volume for 1895 have been issued in separate form. The nineteenth volume of Proceedings appeared during the year, and papers 1124 to 1139, inclusive, constituting Volume XX, have been distributed. Part L of Bulletin 39, containing instructions for the collection of scale insects, by Prof. T. D. A. Cockerell, and Circular 48, relating to the collection and preservation of the bones and teeth of the mastodon and mammoth, have been printed.

By your direction 5,800 copies of the Report of the National Museum are now distributed direct from the Museum, out of a total of 7,000 copies allotted by Congress to the Smithsonian Institution and the Museum.

Tennessee Centennial Exposition.—As stated in the last Annual Report, the Museum participated in the exposition held at Nashville from May 1 to October 31, 1897, for the purpose of celebrating the one hundredth anniversary of the admission of the State of Tennessee into the Union. Eighteen of the divisions and sections of the Museum prepared exhibits for this occasion. A description of these exhibits will be given in detail in the full report of the National Museum for the present year.

Trans-Mississippi and International Exposition.—An exhibit was prepared by the Museum for the Trans-Mississippi and International Exposition which opened at Omaha on June 1, 1898. For this exposition Congress appropriated $62,500 for the erection of Government buildings and $137,500 for the exhibits of the various Executive Departments and Bureaus. Of the latter amount the sum of $19,491.71 was allotted to the Smithsonian Institution and its dependencies. Dr. F. W. True represents the Smithsonian Institution and the National Museum on the Government board of management, and Mr. W. V. Cox acts as special agent in charge of the exhibit. The report for the coming fiscal year will contain a complete description of the collections which have been sent to Omaha by the Museum.

It was with no little regret that I advised you of the necessity of my relinquishing the charge of the National Museum at the close of the present fiscal year. The temporary appointment which you tendered me early in 1897 was accepted with mingled feelings of satisfaction and hesitation. My admiration for the late Dr. Goode and my long and pleasant acquaintance with him and his associates rendered the difficult task lighter than I anticipated, and now, in resigning the charge of the Museum—although I gladly retain the honorary curatorship of the collections in stratigraphic paleontology—I desire to express my sense of indebtedness for the honor which you have conferred upon me and my wish for the ever-increasing prosperity of the National Museum.

Respectfully submitted.

CHAS. D. WALCOTT,

Acting Assistant Secretary in charge of the United States National Museum.

Mr. S. P. LANGLEY,

Secretary of the Smithsonian Institution.

JUNE 30, 1898.

Appendix II.

REPORT OF THE DIRECTOR OF THE BUREAU OF AMERICAN ETHNOLOGY FOR THE YEAR ENDING JUNE 30, 1898.

Sir: I have the honor to submit the report of the Bureau of Ethnology for the year ending June 30, 1898.

In response to your request that the report shall begin with the following statements:—

1. The amount, kinds, and classes of property belonging to the Bureau;

2. The amount of such property acquired during the twelve months covered by the report;

3. The extent and kind of improvements made in the building and grounds during the past year, and the estimated cost;

4. The extent and character of the losses of property, and the origin and causes—

I have the honor to say that the property of the Bureau is, with the exception of one or two items, small in amount and value. By far the most important and valuable property in the custody of the Bureau is the collection of manuscript records, representing a considerable part of the work of the collaborators and the contributions of correspondents during the last twenty years, as well as the collection originally acquired from the Smithsonian Institution. The greater part of the manuscripts are linguistic, and these are not in condition for publication, though invaluable for purposes of study and comparison. The entire collection, embracing more than 2,000 titles, is catalogued and arranged in fireproof vaults in the offices of the Bureau. A strict custody is maintained, under the immediate supervision of the Director.

A related class of property comprises photographs of Indian subjects. So far as practicable, these are represented by the original negatives with a systematic series of prints. The collection comprises about 5,000 negatives, with about 3,000 prints, including 800 prints from negatives which are not in the possession of the Bureau. The collection is in constant use in connection with the preparation of illustrations for the reports; its custody is vested in the illustrator of the Bureau.

Among the minor items the most important is the library of 7,900 volumes and over 5,000 pamphlets, with plain wooden cases sufficient to accommodate them. The greater part of the library represents the product of exchange, and in addition there is a fair collection of books of reference and standard works on ethnologic subjects obtained by purchase. The library is in immediate charge of Mr. F. W. Hodge.

A class of property of some importance is the accumulated residue of publications. The greater part of the edition of the reports available for distribution by the Bureau is sent to exchanges and correspondents immediately on issue, but a limited number of copies of each edition remains for distribution in accordance with subsequent demands. The residue of the several editions not completely exhausted is kept under the supervision of Mr. F. W. Hodge. The editions of most of the reports are exhausted; the undistributed residue numbers about 4,300 volumes.

A somewhat important class of property, though of limited value, is office furniture, with the requisite stationery for current use, as well as photographic apparatus and material. The aggregate value of the furniture and apparatus is less than $2,500. The custody and use of furniture, apparatus, stationery, and other materials are regulated by a custodial system devised for the purpose, which has been found to work satisfactorily.

A considerable number of original engravings used for the illustration of reports are catalogued and arranged in cases in the office of the Bureau, while the original copy for illustrations is also preserved, so far as practicable, in charge of the illustrator. The stereotyped plates from which the reports are printed are from time to time turned over to the Bureau by the Public Printer. These are stored partly in the Smithsonian building, partly in the basement of the building in which the office is located.

Experience has shown that, under existing conditions, it is inexpedient to acquire field property in any considerable amount, since the cost of purchase and maintenance of animals, vehicles, and camp equipage exceeds the charges for hire; accordingly, there is practically no field property in the possession of the Bureau.

The collaborators engaged in field operations collect ethnological material, in greater or less quantities, for purposes of study. All such material is transferred to the National Museum, and commonly the requisite studies are conducted within that building.

During the last fiscal year satisfactory progress was made in enriching the manuscript collections, the series of photographs, and the collections of material objects for the Museum, as indicated in other paragraphs. The aggregate expenditures for stationery and laboratory supplies were $1,900; for furniture, $750, and for the purchase of necessary books of reference and standard works, $850.

The Bureau is domiciled in rented quarters, i. e., the sixth floor of the Adams Building, 1333–1335 F street, Washington. These quarters are limited, hardly meeting the requirements of the work. During the winter, when office work is in active progress, it is sometimes necessary for as many as two or three collaborators to work in private quarters, while some of the permanent property (stereotype plates, etc.) of the Bureau is stored in the Smithsonian and National Museum buildings, and the publications are stored in and distributed from the basement of the building occupied by the United States Geological Survey, through the courtesy of the Director, Hon. Charles D. Walcott.

Ethnologic researches have been conducted during the fiscal year ending June 30, 1898, in accordance with the act of Congress making provision "for continuing researches relating to the American Indians, under the direction of the Smithsonian Institution," approved June 4, 1897.

The work has been carried forward in accordance with a plan of operations submitted on June 14, 1897. The field operations of the Director and the collaborators have extended into Arizona, Chihuahua, Coahuila, Indian Territory, Maine, New Brunswick, New Mexico, New York, Oklahoma, Ontario, and Texas, while special agents have conducted operations in Alaska, Argentina, British Columbia, California, Chile, Greenland, Oregon, and Washington State. The office work has included the collection of material from Indian tribes in Arizona, Idaho, Indian Territory, Kentucky, Minnesota, Montana, Nebraska, North Dakota, New York, Oklahoma, Pennsylvania, South Dakota, and Texas. The researches in the office have dealt with material from nearly all of the States and from other portions of the American continent.

The organization of the work has grown out of a classification of ethnic science based on the researches of the Bureau. It is worthy of note that, while the science of man has advanced rapidly during the last twenty years through the efforts of able investigators in different countries, the advance has been particularly rapid in the United States. No small part of this advance must be ascribed to the farsighted governmental policy of maintaining researches among the aboriginal tribes of the American continents, yet a part of the progress would seem to be due to the wide range in ethnic phenomena with which American students are favored. The investigator in this country may easily come in contact with representatives of every race—of every important strain of blood. At the same time he may study every important grade in culture, from the savagery of some of the Indian tribes, through the barbarism of others, up to the civilization and enlightenment represented by the better part of our population. One of the consequences of this favorable condition for study has been the stimulation of observation and the encouragement of strictly scientific methods of research. Another result is found in the amassing of trustworthy data in unequaled amount for comparative study. The general result is expressed in extension and refinement of ethnic science, and to some extent in the application of ethnology to practical affairs.

The systemization of the science which results from a consideration of its subject-matter as exhibited in the operations of the Bureau was set forth somewhat fully in the last report, and it is followed in the present report. The science for which the Bureau was organized under the act of Congress treats but slightly of the somatic characteristics of the native tribes of America. Its researches extend rather over those characteristics exhibited by men in the tribal state as they are portrayed in cultural elements. These elements of character arise in the methods pursued by the tribesmen for the purpose of securing pleasure, welfare, justice, expression, and opinion. The pursuits involve activities which are esthetic, industrial, governmental, linguistic, and educational, and these give rise to the sciences of esthetology, technology, sociology, philology, and sophiology.

FIELD RESEARCH AND EXPLORATION.

At the beginning of the fiscal year the Director was engaged in an examination of certain shell mounds on the coast of Maine reconnoitered during the preceding season. Limited collections were made, but the associations were noted with care and compared with those characteristic of the Indians still living in the vicinity. The work resulted in the complete identification of the mound builders with the tribes found on the same coast by white men early in the settlement of this country.

During July Mr. F. W. Hodge repaired to Arizona, joining Dr. Fewkes during the excavation of the ruins near Snowflake, south of Holbrook, and later accompanying him to Tusayan for the purpose of gaining further insight into the summer ceremonies of the Hopi Indians and additional knowledge of the ruins of their former villages. Leaving Dr. Fewkes and his party late in August, he visited the remarkable, but little-known, ruins on the mesas surrounding Cebollita Valley, about 35 miles south of Grant, N. Mex., making photographs of noteworthy features and ground plans of some of the more interesting structures. After spending several days in this work Mr. Hodge visited the pueblos of Laguna and Acoma, witnessing, at the latter village, the interesting Fiesta de San Estevan, and, on September 3, proceeded with his party to the widely known Mesa Encantada, some 3 miles from Acoma, the traditional home of these Indians during prehistoric times. The precipitous height was climbed, the night was spent on the summit, and after carefully examining its entire surface Mr. Hodge was successful in finding ample traces of Indian occupancy at a remote period. He also found traces of an ancient pathway leading toward the summit, and quantities of prehistoric ware in the talus, to which it had evidently been washed from the summit of the mesa; accordingly he was able to substantiate the essential features of an Acoma tradition.

The beginning of the year found Dr. J. Walter Fewkes occupied in collecting aboriginal material from a prehistoric ruin known as Kintiel, or Pueblo Grande, located on an upper wash of the Colorado Chiquito, between Navaho station and Ganado, in eastern central Arizona. Situated midway between the Tusayan and Zuñi groups of pueblos, the origin of this ruin has for a number of years been a problem to investigators in this field; but the researches of Dr. Fewkes show quite conclusively that the art remains unearthed resemble more closely those of Haloua, Heshotauthla, and other ancient Zuñi villages than those of the prehistoric pueblos of Tusayan. Excavations were conducted in the cemeteries, as well as in the ruin of the village, in each of which an interesting collection of pottery and bone and stone implements was unearthed.

Fully satisfied with the results at this point, Dr. Fewkes returned to the railroad, and from Holbrook proceeded to the vicinity of Pinedale, near the northern border of the White Mountain Apache Reservation, where another interesting collection of objects was made. Although the ruins from which they were recovered are more remote from the present Tusayan villages than are those of Kintiel, they are more closely similar in form and in symbolic decoration to ancient Tusayan art products than are the specimens obtained from the latter place.

Excavations were next conducted in an interesting ruin about 4 miles west of Snowflake, which, like those of Pinedale, were hitherto unknown to archæologists. Researches at this point extended over a period of a fortnight, being conducted both in the house ruins and in the cemeteries northward and southwestward thereof. An unusually large collection of fictile ware, as well as a very interesting but smaller collection of bone, stone, and shell objects, were here recovered. By the middle of August Dr. Fewkes returned with his party to Holbrook, and proceeded thence to the Tusayan villages, where he made observations supplementary to those conducted in previous years in connection with the Snake Dance and related ceremonies.

During September Dr. Fewkes visited that part of the upper Gila Valley called Pueblo Viejo, and examined the exterior ruins in that region discovered and described by Emory and Johnston in 1846. He conducted archæological work in mounds near Solomonville and San Jose de Pueblo Viejo, and collected several hundred objects from these localities. These ruins were found to bear close architectural resemblance to those near Phœnix and Tempe, and to indicate adobe houses with walls supported by logs and stones, clustered about a central building which served for protection or for ceremonial purposes. Pottery and other objects from these ruins were found to be identical with those from near Casa Grande. It was discovered that the ancient people of this valley sometimes buried their dead in their houses, but that the larger number were cremated. The calcined houses and ashes of the latter were placed in decorated jars and buried in pyral mounds. Remains of extensive prehistoric irrigating ditches, reservoirs, and terraced gardens show that the valley was extensively farmed in ancient times, and the large number of ruined houses indicate an extensive population. An instructive collection of pottery, beads, shells, and sacrificial objects was obtained from a cave in the mountains north of Pueblo Viejo.

During a part of his field season Dr. Fewkes had the aid of Mr. F. W. Hodge, and during the entire summer the assistance of Dr. Walter Hough, of the United States National Museum. The researches of Dr. Fewkes conducted during this summer were remarkably successful both in the extent and value of the collections acquired and in the archæologic and ethnologic data recorded.

Toward the end of September Mr. James Mooney took the field in New Mexico, Texas, and contiguous Mexican States for the purpose of collecting, among various tribes, information additional to that obtained among the Kiowa and Kiowa-Apache of Oklahoma concerning the primitive rites in which peyote, more popularly known as "mescal," is used as a narcotic and stimulant. Incidentally to this work, Mr. Mooney made a brief visit to a series of interesting pueblo ruins, attributed to the neighboring Tewa Indians, on a mesa 12 miles westward from Espanola, above Santa Fé, on the Rio Grande, in New Mexico. These remains are of considerable local repute, but thus far they have not been seriously excavated.

The Jicarilla Apache, numbering 850 on a reservation in northern New Mexico, were the next object of Mr. Mooney's attention. This tribe formerly roamed over the section eastward of the mountains of New Mexico, on the head waters of Arkansas and Canadian rivers, but affiliated with the Ute rather than with the plains tribes. It was found that they knew of the peyote only through temporary association with the Mescalero a few years ago when the two tribes were for a time on one reservation. The Mescalero Apache, numbering 450 on a reservation in southeastern New

Mexico, were next visited. These Indians, whose popular name is derived from their use of the "mescal" or peyote, are regarded by the plains tribes as masters in all that concerns the plant, but from information received through their best informants, as well as from actually witnessing the ceremony, Mr. Mooney found the rite to be declining among them, largely through the difficulty of procuring the plant in their isolated condition, as it requires five days' journey on horseback to obtain a necessary supply. Living with the Mescalero, Mr. Mooney discovered a number of Lipan and a few Kiowa-Apache Indians. The Lipan were a predatory tribe of eastern Texas and were practically exterminated some thirty years ago on account of their raiding propensities against both Texas and Mexico. Of the remnant a few are incorporated with the Tonkawa, a few joined the Mescalero and Kiowa-Apache, while others, probably the larger number, fled to the Santa Rosa Mountains, in northern Mexico, where they still live. Mr. Mooney obtained through the Lipan further information in regard to several Texan tribes, including the Karankawa and Tonkawa, of whom little has been known, and from them also definite information was obtained in regard to the use of peyote among the Tarahumari of Mexico.

Having completed his investigations among the tribes of New Mexico in the early part of December, Mr. Mooney devoted attention to the remnants of the Piro, Tiwa, Suma, and Manso tribes on the Rio Grande, below El Paso, in Texas and Chihuahua. These Indians, now practically Mexicanized, are the descendants of a large number of natives who were taken by Governor Otermin on his retreat from Santa Fé to El Paso and settled at their present location during the Pueblo rebellion in 1680. He obtained valuable information in regard to the former status of these people, and conducted also some linguistic researches to which reference will later be made.

Mr. Mooney next proceeded to the mountain country of Texas, southeastward from El Paso, for the purpose of locating the peyote from information given by the Mescaleros. Two or more varieties of the plant were found in this section, on both sides of the Rio Grande. In January Mr. Mooney continued southward to the Tarahumari country in quest of additional information concerning the rites and customs of that tribe of which peyote forms the feature. The Tarahumari is one of the most populous tribes in North America, their number being variously estimated at from 50,000 to 80,000; they occupy nearly the whole mountain region of the State of Chihuahua. They perform a number of interesting ceremonies in which the peyote plays an important role; indeed, the plant is a prominent part of the medicine man's stock in trade, rather than something used by the tribe at large, as among the Kiowa and associated tribes to the northward. Several varieties of the peyote are recognized by the Tarahumari, who procure the plant chiefly about Santa Rosalia, in southeastern Chihuahua. Information concerning the ceremonial use of the peyote by the neighboring Tepehuan tribes was likewise gained, and the southernmost limit of its use in Mexico was also determined.

Aside from his researches in this interesting subject, Mr. Mooney made an examination of some large burial caves near Aguas Calientes, about 200 miles southwestward from Chihuahua city. Although the principal one of these caves had been excavated by residents in the hope of finding buried treasure, and their contents thereby disturbed, Mr. Mooney succeeded in recovering a well-preserved mummy with its original wrappings of matting and native cloth and the accompanying food and water vessels, which have been deposited in the National Museum. These and kindred observations throw much light on the little-known mortuary customs of the region.

During August and September Dr. Albert S. Gatschet was occupied in linguistic researches begun during the preceding year among the Algonquian tribes in Maine and contiguous parts of New Brunswick. His work resulted in the enrichment of his vocabularies and in the preparation of numerous texts, valuable not only as indices of linguistic structure, but as records of tribal history, customs, social organization, and beliefs.

Mr. J. N. B. Hewitt spent the autumn in the field in northern New York and neighboring parts of Ontario, collecting linguistic and sociologic data required for the full comparative study of the Iroquoian tribes. He was also able to obtain new and valuable additions to the series of creation myths for which these Indians are notable, and through which their names have become extensively incorporated in the literature of the world.

On November 4, 1897, Mr. J. B. Hatcher, of Princeton University, who was about to sail for Argentina, was specially commissioned to make collections among the Indian tribes of South America; and toward the end of the fiscal year he sent his first shipment of material, representing the natives of Patagonia, whose characteristics have attracted attention for centuries.

On January 11, 1898, Mr. Gerard Fowke was employed temporarily to make archæological surveys and excavations in an interesting locality in Kentucky. These excavations were particularly successful, yielding a considerable quantity of valuable archæologic material, which has been placed in the National Museum.

Shortly before the opening of the fiscal year Dr. Robert Stein, attached to Lieut. R. E. Peary's Arctic expedition for the purpose of exploring a little-known stretch of the coast of western Greenland, was commissioned to make archœological researches and collections. He was landed on August 10, 1897, and remained until September 1, when he was taken up by Lieutenant Peary on his return trip. During Dr. Stein's stay on a part of the coast not now inhabited, he discovered abundant traces of ancient habitation by the Eskimo, and collected a quantity of somatologic and other material.

The objective material collected during these explorations has been placed in the National Museum; the new data have been added to the archives and incorporated in memoirs now in preparation or completed for publication, as indicated in other paragraphs. The scientific results of the work are summarized in the following pages.

Office Research.

WORK IN ESTHETOLOGY.

Mr. Frank Hamilton Cushing has continued the study and arrangement of his collections of aboriginal handiwork from western Florida, and has made progress in the preparation of a report on the prehistoric key-dwellers of the eastern shore of the Gulf of Mexico. During the greater part of the year the collections were kept in the Museum of Archæology of the University of Pennsylvania, where they were shipped on account of the inadequate space then afforded by the National Museum for unpacking and assembling; toward the end of the fiscal year, as the capacity of the Museum was increased by the introduction of galleries, the greater part of the collection was brought to Washington and arranged in cases and on tables for purposes of comparison and study. In the course of his work Mr. Cushing has made extensive comparisons between his specimens and those obtained by other archæologists from different portions of the United States, and the comparative studies are highly significant. The Florida collections are rendered exceptionally valuable by reason of the large number of specimens made from and decorated with animal and vegetal substances, which are ordinarily perishable, though preserved in high perfection in the muck-beds associated with the Florida Keys. Accordingly, the material serves better than any other collection thus far made to connect the records of the early explorers with the observations of later times; at the same time it serves to round out knowledge concerning the pre-Columbian handiwork of the Indians in all of the softer, more flexible, and more easily destructible substances, and accordingly permits comparison of designs wrought in a wide range of materials.

Dr. J. Walter Fewkes has continued the preparation of reports on his archæologic researches in Arizona and New Mexico. These researches were undertaken primarily for the purpose of enriching the collections of aboriginal art products for the National Museum. The large collections embrace a remarkably complete series of primitive designs and motives in fictile ware, including the adaptation of mythologic, animal, bird and feather, insect, and reptilian figures. Many of these are so highly conventionalized that they would have been practically uninterpretable without the knowledge of Tusayan mythologic and sociologic concepts which Dr. Fewkes fortunately possesses; consequently he has been enabled to make substantial contributions to knowledge of the development of artistic concepts, the results of which are incorporated in two memoirs for publication, respectively, in the seventeenth and nineteenth annual reports.

In connection with other researches, Mr. W J McGee has made inquiries from delegations of Indians visiting Washington concerning the symbolic use of feathers, especially in connection with headdresses. It is well known to students that the use of feathers, which, at first sight, would seem to be decorative merely, is essentially symbolic; but the meanings of the symbols have not been ascertained hitherto, save casually and among a few tribes. During the year, the feather symbolism of the Ponka and Ojibwa tribes has been discovered and recorded with tolerable completeness.

WORK IN TECHNOLOGY.

Arts and industries are correlated factors in human progress, and the lines of conceptual development traced through the study of art motives elucidate the growth of industrial devices. Accordingly, the work of the collaborators in connection with art motives has contributed both directly and indirectly to aboriginal technology. During the year special attention was given to lines of technical development, as indicated in previous reports and in the acquisition of material for study and preservation in the Museum. Especially valuable is the Steiner collection, from the mounds of Etowah Valley, Georgia. It comprises 3,215 specimens of stone implements, earthenware, and symbolic and decorative objects of copper, shell, and stone. The Indians of this district, builders of the great Etowah mound and other monuments, were peculiarly fertile in artistic and industrial devices. In this region the progressive tribes of the Siouan stock, the vigorous Cherokee, one or more of the wide-ranging Algonquian tribes, the little-known Yuchi, and some of the Muskhogean tribes came in frequent contact, while the influence of the arts and industries of the key-dwellers of Florida was constantly felt. Here, as elsewhere, ideas and ideals were stimulated by contact, whether peaceful or not, and the devices representing the rapidly growing concepts are especially significant and useful in tracing the course of industrial development among the aboriginal tribes. Another noteworthy acquisition is the Morris collection from Arkansas, comprising 181 pieces of pottery, together with a number of stone implements and other objects. The collection is especially valuable as an illustration of types of pottery hitherto rare or unknown. But the most important acquisition of archæologic objects procured during the year is comprised in the collections made by Dr. J. Walter Fewkes from the ruins of Kintiel, Pinedale, Four-mile, Solomonville, and others in eastern and southern Arizona and southwestern New Mexico, an elaborate report on which is now being prepared. Like the collections obtained at Sikyatki, Awatobi, and other Tusayan ruins, these include fictile and textile products, stone, bone, and wooden implements, and objects of shell and stone used for personal adornment. In symbolic decorative features the mortuary food and water vessels, as well as many of the utensils recovered from the houses, are exceedingly rich. The collections have been deposited in the National Museum.

The process of culture in all the five departments is by invention and acculturation. The invention is at first individual, but when invention is accepted and used by others it is accultural, and the invention of the individual may be added to the invention of others, so that it may be the invention of many men. Objects may be used without designed modification, or they may be designedly modified for a purpose. The use of objects without the designed modification of them has been appplied to Seri stone implements by Mr. McGee, when he calls such modified implements protolithic, while the modified stone implements he calls technolithic. The two phases are widely distinct, not only in type of object, but even more in the mental operations exemplified by the objects; for the protolithic objects represent undesigned adaptation and modification of cobbles picked up at random, while the others represent designed shaping in accordance with preconceived ideals. The coexistence of the incongruous types seemed puzzling at the outset, but was provisionally ascribed to the difference in occupation between the sexes, the women using the protolithic implements and the warriors making and using the technolithic weapons. Further study showed that the objects of chipped stone imitate in every essential respect the aboriginal weapons of the hereditary enemies of the Seri, including the Papago and Yaki; and this fact, coupled with the mysticism thrown around the stone arrowpoints by the Seri shamans, indicated that the idea of the technolithic weapon was acquired through warfare. Examination of other characteristics of the Seri in the light of this interpretation served to explain various puzzling features and at the same time established the validity of the interpretation. The Seri have been at war with alien tribes almost constantly since the time of Columbus, and indeed long before, as indicated by archæologic evidence. Most of their arts and industries are exceedingly primitive; yet here and there features imitating those characteristic of neighboring tribes, or even of white men, are found. Thus they use ollas for carrying water which are fairly distinctive in type, though apparently based on alien models, yet make no other use of baked clay. They substitute cast-off rags and fabrics obtained by plunder for their own fabrics, wrought with great labor from inferior fibers. Since the adjacent waters have been navigated they have learned to collect flotsam, using tattered sailcloth in lieu of pelican-skin blankets, cask staves in lieu of shells as paddles for their balsas, hoop-iron in lieu of charred hardwood as arrowpoints for hunting, and iron spikes in lieu of bone harpoons for taking turtles; and almost without exception these modifications in custom have arisen without amicable relation and despite—indeed largely by reason of—deep-seated enmity against the alien peoples.

SOCIOLOGY.

In sociology Mr. McGee has observed some interesting facts which give light on the development of institutions among the tribes of America, especially in the acculturation that spreads from one unfriendly tribe to another, which he calls piratical acculturation. The Apache and Papago tribes have been bitterly inimical from time immemorial, the oldest creation legends of the Papago describing the separation of the peoples in the beginning; yet there is hardly a custom among them which has not been shaped partially or completely by the inimical tribe. The habitat of the Papago in the hard desert is that to which they have been forced by the predatory Apache; the industries of the Papago are shaped by the conditions of the habitat and by the perpetual anticipation of attack; the traditions recounted by the old men are chiefly of battle against the Apache; even the ceremonies and beliefs are connected with that eternal vigilance which they have found the price of safety, and with the wiles and devices of the ever-present enemy. Perhaps the most important element in the acculturation is that connected with belief, for to the primitive mind the efficiency of a weapon is not mechanical but mystical, an expression of superphysical potency, and each enemy strives constantly to coax or suborn the beast-gods and potencies of the other; so the Papago warrior went confidently to battle against the Apache when protected by a charm, or fetish, including an Apache arrowpoint taken in conflict, and felt assured of victory if his warclub was made in imitation of that of the enemy and potentialized by a plume or inscription appealing to the Apache deity. Even later in the scale of development, after the piratical acculturation is measurably amicable, this factor remains strong, as among the clans of the Kwakiutl and some other tribes in which the aim of marriage settlement is the acquisition, not of property or kindred per se, but of gods and traditions concerning them. The general law of piratical acculturation finds innumerable examples among the more primitive peoples of the world, and phases of it have been recognized in the proposition that conquering tribes take the language of the conquered. Other phases have been perceived, e. g., in the hypothesis of primitive "marriage by capture." Various earlier students have noted that actual or ceremonial capture of the bride is a part of marriage among certain tribes, and have assumed that this was the initial form of mating among primitive peoples; later researches have shown that, in the lowest of the four great culture stages, mating is regulated by the females and their male consanguineal kindred, so that marriage by capture of brides can not occur; yet there is a step early in the stage of paternal organization in which a certain form of marriage by capture has arisen in America, and may easily have become prominent on other continents. When tribes are in that unstable condition of amity resulting in peaceful interludes between periods of strife—a stage characteristic of savagery and much of barbarism—the intertribal association frequently results in irregular matches between members of the alien tribes; commonly such mating is punished by one or both tribes, though among many peoples there are special regulations under which the offense may be condoned—e. g., the groom may be subjected to fine, to running the gantlet, to ostracism until children are born, etc. Yet while both bride and groom incur displeasure and even risk of life through such matches, there is a chance of attendant advantage which may counterbalance the risk; for it frequently happens that the groom, especially if of the weaker tribe, eventually gains the amity and support of his wife's kinsmen, while in some cases the elder men and elder women of one or both tribes recognize the desirability of a coalition which can tend only to unite the deities of both, and so benefit each in greater or lesser measure. Researches among the American aborigines have already shown that, so far as this continent is concerned, exogamy and endogamy are correlative, the former referring to the clan and the latter to the tribe or other group; they have also shown that the limitations of exogamy and the extension of endogamy are ingenious devices for promoting peace; and it is now becoming clearer that intertribal marriage, whether by mutually arranged elopement or by capture of the bride, may be a means of extending endogamy and uniting aliens, and thereby of raising acculturation from the piratical plane to that of amicable interchange. The applications of the law of piratical acculturation are innumerable. In the light of the law, it becomes easy to understand how inimical tribes are gradually brought to use similar weapons and implements, to adopt similar modes of thinking and working, to worship similar deities, and thus to be brought from complete dissonance to potential harmony whensoever the exigency of primitive life may serve; and thus the course of that convergent development, which is the most important lesson the American aborigines have given to the world, is made clear. Some idea may be formed, also, of the history of piratical acculturation.

WORK IN PHILOLOGY.

Dr. Albert S. Gatschet has continued the preparation of a comparative vocabulary of Algonquian dialects, making satisfactory progress. The Algonquian linguistic stock was the most extensive of North America, both in the number of dialects and in the area occupied by the tribes using them. For this and other reasons the stock has been a source of much labor among philologists, and there has been considerable diversity of opinion as to its classification. One of the tasks undertaken by the Bureau early in its history was the review of Algonquian linguistic material for the purpose of formulating a definite and satisfactory classification. Many vocabularies have been collected and compared; to aid in the determination of affinities, grammatic material has also been obtained in considerable volume; and still further to elucidate relations, a body of records of myths and ceremonies has been accumulated. The lexic, grammatic, and mythologic records of the Algonquian stock collected by collaborators of the Bureau and obtained from correspondents form several hundred manuscripts; and it is from this voluminous material that the comparative vocabulary is compiled. In addition to this routine work on the vocabulary, Dr. Gatschet has from time to time prepared linguistic material for use in answering inquiries of numerous correspondents.

Mr. J. N. B. Hewitt has continued the study of the Iroquoian language during the year. As noted in former reports, he has also carried forward a general study of the pronoun as used in primitive tongues, with a view to the preparation of a memoir on linguistic development. Partly as a means to this end, partly because of the inherent interest of the subject, he has undertaken a comparative study of the creation myths of the Iroquoian and some other tribes. During the latter portion of the year the greater part of his time has been devoted to this study, with highly satisfactory results.

During his operations among the Mescalero and Jicarilla Apache tribes of New Mexico, mainly for the purpose of gaining knowledge concerning the ceremonial use of the peyote among those people, as recorded in previous paragraphs, Mr. James Mooney accepted the opportunity of obtaining vocabularies for comparison with cognate dialects together with their genesis myths. The Mescalero and Jicarilla dialects are practically the same, and the cosmogony of the two tribes is also nearly identical, although they were generally at war with each other, the Mescalero cooperating with the plain tribes while the Jicarilla were allies of the Ute. Owing to the fact that the Lipan were exterminated nearly a generation ago, and by reason of the isolation of the surviving remnants, doubt has been expressed as to their true affinity, but from a vocabulary obtained by Mr. Mooney from members of this tribe associated with the Mescalero on their reservation, it is now known that they speak a well-defined Athapascan dialect. Such linguistic researches as the present meager knowledge of their language would permit were also conducted by Mr. Mooney among the modified Tiwa and Piro Indians on the Rio Grande below El Paso.

Returning from the field for the purpose of revising proofs of a memoir on the Calendar History of the Kiowa Indians, in course of composition as a part of the seventeenth annual report, Mr. James Mooney remained in the office during the last quarter of the year, occupied, in the intervals of proof reading, in the translation and arrangement of a large collection of Cherokee myths recorded in the original syllabary as well as in the English. Satisfactory progress was made in preparing the material for publication.

During the later part of the year the researches in Indian sign language, which were brought to a close by the death of Colonel Mallery in 1894, were resumed through the collaboration of Capt. Hugh L. Scott, U. S. A. Captain Scott was stationed for some years on the frontier, where he was in constant contact with various Indian tribes, including the plains Indians, among whom the sign language was highly developed. Early in his stay he became interested in the signs and began acquiring this interesting art of expression, and his studies continued until he became proficient and able to use the sign language habitually in communicating with various tribes. His knowledge of the system is undoubtedly superior to that of any other white man, and his acquaintance with individual signs exceeds that of any Indian with whom he has come in contact. During the winter Captain Scott was transferred to Washington, and through the courtesy of the Secretary of War and the Commanding General of the Army he was authorized to take up the record and discussion of sign language under the direction of the Bureau. Considerable progress had been made in the work when it was interrupted by conditions connected with the war with Spain.

WORK IN SOPHIOLOGY.

The Director continued the development of a system of classification designed to indicate the place of the American Indians among the peoples of the earth; during the latter part of the year he took up the voluminous material in the Bureau archives relating to aboriginal mythology. While in charge of the United States Geographical and Geological Survey of the Rocky Mountain region, before the Bureau was instituted, the Director began the collection of myths among the Indians of the Territories, and when the Bureau was created this material, in connection with a body of linguistic manuscripts obtained by the Smithsonian Institution, formed the original archives. Additional material was collected from time to time by the Director and by several of the collaborators, and there are now some hundreds of manuscript records ready for study. Satisfactory progress has been made in the preliminary arrangement of the manuscripts and in the extraction and classification of salient features in the primitive mythology prevailing among all of the native tribes before the advent of the white man.

Mrs. Matilda Coxe Stevenson has continued the final revision of her manuscript for a memoir on the Zuñi Indians, designed for incorporation in the nineteenth annual report. Most of the chapters are now complete, and nearly all of the illustrations are ready for reproduction. The Pueblo Indians well illustrate certain results of environment in the development of belief and ceremony. A harsh environment begets profound faith; this is illustrated by the history of many cults. The Pueblo region was a gathering ground of primitive faiths, each fertilizing the others in accordance with the law already set forth and each intensified by hard local conditions. The northern tribes, who furnished much of the blood of the Pueblo peoples, were pressed down from more humid regions and brought into conflict with alien warriors and with an arid habitat in which the specters of thirst and famine were ever present; the southern tribes, who furnished most of the culture of the Pueblos, were in part at least forced up toward the plateaus from the still more arid districts about the present national boundary into which they had fled, as the excess of population from the more fertile districts of pre-Columbian Mexico. All of the peoples were shadowed by the dangers of drought and by the hard labor required for the maintenance of existence; all were accustomed to invocations for rain; all were accustomed to ceremonies connected with the growth of corn; all were accustomed to reverence of beast-gods, and all ascribed their preservation from ever-present danger to their success in propitiating the maleficent mysteries by which they were surrounded—for that which is simply a hard natural condition to the advanced thinker is always a maleficent potency to the primitive thinker. All of the circumstances were such as to develop a profoundly devotional cast of mind among the Pueblo peoples; and their myths and ceremonies became so striking as to attract the attention of students throughout the world, as white men came in contact with them. Mrs. Stevenson's researches concerning the myths and ceremonies have been exceptionally thorough, and the results now nearly ready for publication will form a substantial contribution to the knowledge of aboriginal mythology.

DESCRIPTIVE ETHNOLOGY.

During the year the important work of compiling a Cyclopedia of Indian Tribes of North America was continued by Mr. F. W. Hodge, with the assistance of Dr. Cyrus Thomas, the former carrying forward the work in connection with other duties. Dr. Thomas completed the preliminary arrangement of the material relating to the tribes of the Algonquian stock, submitting the material for editorial revision. He afterward took up the manuscript and literature relating to the tribes of the Siouan stock, and has made satisfactory progress in the arrangement of the material.

COLLECTIONS.

A number of collections have been acquired during the year under the more immediate direction of the Secretary. Some of these are noted above; in addition there have been acquired (1) a collection of Jamaican antiquities by MacCormack, including 160 specimens of ancient stone implements, earthenware, etc., and 20 petaloid implements; (2) the Palmer collection of 98 ethnologic specimens from Mexico, and (3) the Gane collection of cliff-house relics, comprising fictile ware, bone implements, etc., from San Juan Valley, Utah. In addition, the Muñiz collection of trephined skulls, illustrated and described in the sixteenth annual report, was finally transferred to the Museum. A considerable number of separate objects and minor collections obtained by exchange for reports and by gift has also been turned over to the Museum during the year; among these was a Muskwaki hand-loom obtained by Mr. McGee for the express purpose of filling an hiatus in the national collection.

PUBLICATION.

Satisfactory progress has been made by Mr. Hodge in the revision of the proofs of the seventeenth and eighteenth annual reports and in the editorial work on the manuscript of the nineteenth annual report. The seventeenth report was transmitted to the Public Printer by the Secretary of the Smithsonian Institution on July 6, 1897, the first proofs being received on September 20, and by the end of June, 1898, the two volumes comprising the work were practically all in type. In addition to the usual account of the operations of the Bureau the seventeenth annual report will contain four memoirs, bearing the titles, "The Seri Indians," by W J McGee; "Calendar History of the Kiowa Indians," by James Mooney; "Navaho Houses," by Cosmos Mindeleff, and "Archæological Expedition to Arizona in 1895," by J. Walter Fewkes.

The eighteenth annual report was transmitted to the Public Printer by the Secretary on March 11, 1898. It comprises, in addition to the report of operations for the fiscal year 1896–97, two papers entitled, respectively, "The Eskimo About Bering Strait," by E. W. Nelson, and "Indian Land Cessions in the United States," by C. C. Royce. Like the seventeenth annual report, this also will appear in two volumes. The first galley proofs were received from the Public Printer in the latter part of June.

While all the material for the nineteenth annual report is not yet in hand, satisfactory progress has been made in its preparation, and it is believed that a sufficient number of memoirs have already been received from the collaborators of the Bureau to warrant the publication of the report in at least two volumes. These memoirs are: "Cathlamet Texts," by Franz Boas; "Archæological Researches in 1896 and 1897," by J. Walter Fewkes; "Tusayan Snake and Flute Ceremonies," also by Dr. Fewkes; "Localization of Gentes," by Cosmos Mindeleff; and "Aboriginal American Architecture," also by Mr. Mindeleff. It is expected that several other noteworthy papers will be received from their authors in ample time for incorporation as a part of this report.

BIBLIOGRAPHY.

As set forth in a previous report, the bibliography of the aboriginal languages of Mexico, which was left uncompleted at the time of Mr. Pilling's death, has been continued through the generous services of Mr. George Parker Winship, librarian of the John Carter Brown library at Providence, with the courteous permission of Mr. John Nicholas Brown. The unusual facilities afforded by the excellent library under Mr. Winship's care has enabled him to make marked progress with this work during the fiscal year; much, however, yet remains to be done ere the work will be ready for publication.

MISCELLANEOUS.

Library.—The maintenance of the library has continued under the supervision of Mr. Hodge, and the distribution of the publications of the Bureau has also been conducted under his direction. At the close of the last fiscal year, as mentioned in the report covering that period, the volumes in the library numbered 7,138; to these 756 volumes have been added, making a total of 7,894 volumes at the close of the year. In addition several thousand pamphlets and scientific periodicals have been received.

Illustrations.—The preparation of the illustrations, including the photographic work, was continued under the direction of Mr. Wells M. Sawyer until March 17, 1898, when he resigned to accept another Federal appointment. From that time until the close of the year the preparation of illustrations was conducted under the able supervision of Mr. De Lancey Gill, of the United States Geological Survey, through the courtesy of Hon. Charles D. Walcott, director of that Bureau. During the year about 75 negatives and 610 photographic prints were made for purposes of illustration and exchange. The preservation and cataloguing of the Bureau's negatives have continued with the aid of Mr. Henry Walther.

Respectfully submitted.

J. W. Powell,
Director.

Mr. S. P. Langley,
Secretary of the Smithsonian Institution.

Appendix III.

REPORT ON THE OPERATIONS OF THE INTERNATIONAL EXCHANGE SERVICE FOR THE YEAR ENDING JUNE 30, 1898.

Sir: I have the honor to submit the report of the International Exchange Service for the year ending June 30, 1898.

In response to your request that the report shall begin with the following statements—

1. The amount, kinds, and classes of property belonging to the Exchanges;

2. The amount of such property acquired during the twelve months covered by the report;

3. The extent and kind of improvements made in the building and grounds during the past year, and the estimated cost;

4. The extent and character of the losses of property, and the origin and causes;

I have the honor to say that the property belonging to the International Exchanges is contained in six rooms in the basement of the Smithsonian building. The furniture and fixtures consist of desks, sorting tables, racks, and bins for the assembling and classification of exchanges, the usual appliances of a well-equipped office, a typewriter, shelves for directories and reference books, and several filing cases for systematically arranging all invoices, letters, and the card record of exchange correspondents. This record contains a complete debit and credit exchange account with all persons or institutions corresponding with the service wherever located, and at present embraces the names, addresses, and records of all packages sent to or received from 30,000 correspondents.

Aside from the office equipment above mentioned, it is necessary to constantly carry in stock from 100 to 300 packing boxes, used for the shipment of exchanges abroad, wrapping paper, twine of various sizes, nails and screws in quantity, from 40,000 to 60,000 manila envelopes of various sizes and weights for inclosing books and pamphlets, a large supply of printed cards for indexing, cataloguing, and for the acknowledgments of exchanges, both foreign and domestic.

The office furniture and fixtures represent an original expenditure of about $1,800, and, taking into account the depreciation resultant from use, are at present valued at $1,200. The cost of stationery and supplies on hand averages about $500.

During the twelve months ending June 30, 1898, the cost of materials purchased from the Congressional appropriation for that year aggregated $938.48 and from repayments $1,177.79.

The premises occupied by the exchange service are the property of the Smithsonian Institution and are assigned gratuitously to the exclusive use of the International Exchange Service, together with repairs, which are made by the Institution as they become necessary.

I am pleased to report that during the past year there have been no losses of property and no damages beyond those due to the results of constant use.

Concerning the operation of the service during the year, I have the honor to report that the total number of packages from all sources handled was 84,208, representing an increase of 3,046 in number and nearly 22 per cent in weight over the exchange shipments of the previous year. Of this number, 58,640 packages originated in the United States and were forwarded to 93 foreign countries, while the remainder were received from 40 different countries abroad for distribution in the United States.

There has also been an increase of 1,450 in the number of correspondents, foreign and domestic, which now aggregate nearly 30,000 addresses, representing practically every civilized part of the world.

The work of the service is succinctly given in the following table:

TABULAR STATEMENT OF THE WORK OF THE INTERNATIONAL EXCHANGE SERVICE.

Transactions of the International Exchanges during the fiscal year 1897–98.

Date.	Number of packages handled.	Weight of packages handled.	Number of correspondents June 30, 1898.				Packages sent to domestic addresses.	Cases shipped abroad.
			Foreign societies.	Domestic societies.	Foreign individuals.	Domestic individuals.		
1897.								
July	7,255	33,095						
August	8,299	30,392						
September	3,469	10,244						
October	9,412	29,601						
November	8,280	60,152						
December	4,600	11,634						
1898.								
January	8,537	27,797						
February	5,354	17,292						
March	5,953	15,214						
April	7,826	23,747						
May	6,631	19,936						
June	8,592	22,368						
Total	84,208	301,472	10,165	2,533	12,378	4,382	21,057	1,330
Increase over 1896–97	3,046	54,028	751	88	365	246	a2,562	30

a Decrease.

For the purpose of comparison the following table represents the number of packages of exchanges handled and the increase in the number of correspondents each year from 1892 to 1898:

	1891–92.	1892–93.	1893–94.	1894–95.	1895–96.	1896–97.	1897–98.
Number of packages received	97,027	101,063	97,969	107,118	88,878	81,162	84,208
Weight of packages received...lbs.	226,517	200,928	235,028	326,955	258,731	247,444	301,472
Ledger accounts:							
Foreign societies	6,204	6,896	6,991	8,751	8,022	9,414	10,165
Foreign individuals	7,910	8,554	8,619	9,609	10,878	12,013	12,378
Domestic societies	2,044	2,414	1,620	2,014	2,115	2,445	2,533
Domestic individuals	4,524	5,010	2,993	3,034	3,899	4,136	4,382
Packages to domestic addresses	26,000	29,454	32,931	29,111	34,091	23,619	21,057
Cases shipped abroad	1,015	878	905	1,364	1,043	1,300	1,330

EXPENSES.

The expense of the exchange system is met in part by direct appropriation by Congress to the Smithsonian Institution for that purpose and in part by appropriations to different bureaus of the Government for repayment to the Institution of a portion of the cost of transportation, the rate of which repayment was fixed by the

Board of Regents in 1878 at 5 cents a pound. A similar charge is also made in the case of State institutions. During the past year the total amount available for the support of the service aggregated $25,193.33, of which sum $19,000 was appropriated by Congress and $6,193.33 was derived from repayments.

The appropriation by Congress, being for the fiscal year ending June 30, 1898, and forming an item in the sundry civil act approved June 4, 1897, was made in the following terms:

"For expenses of the system of international exchanges between the United States and foreign countries under the direction of the Smithsonian Institution, including salaries or compensation of all necessary employees, nineteen thousand dollars."

The receipts and disbursements for the year to July 1, 1898, were as follows:

RECEIPTS.

	Congressional appropriation.	Other sources.	Total.
Direct appropriation by Congress	$19,000.00	....	$19,000.00
Repayments from United States Government Departments	....	$6,099.83	6,099.83
Repayments from State institutions	....	93.70	93.70
Total	19,000.00	6,193.53	25,193.53

EXPENSES.

	From Congressional appropriation.	From other sources.	Total.
Salaries and compensation	$15,833.55	$489.27	$16,322.82
Freight	2,187.81	2,476.77	4,664.58
Postage and telegraph	120.00	200.50	320.50
Stationery and supplies	164.23	412.90	577.13
Packing boxes	633.80	240.00	873.80
Traveling expenses	20.45	236.02	256.47
Publication of International Exchange List	....	524.89	524.89
Balance to meet outstanding liabilities June 30, 1898	40.16	1,613.18	1,653.34
Total	19,000.00	6,193.53	25,193.53

CORRESPONDENTS.

The list of correspondents at the close of the year contained 29,458 addresses, being a gain of 1,450 over the preceding year and of 4,544 over 1896. The number in each country is shown in the following table, which also well illustrates the wide extent of the service:

Correspondents of the International Exchange Service.

Country.	Correspondents.			Country.	Correspondents.		
	Libraries.	Individuals.	Total.		Libraries.	Individuals.	Total.
AFRICA.				AFRICA—continued.			
Algeria	21	21	42	Cape Colony	36	54	90
Angola	1	....	1	Cape Verde Islands	....	5	5
Azores	5	14	19	Congo Free State	....	3	3
Beira	....	1	1	Egypt	22	44	66
Canary Islands	1	6	7	French Congo	....	1	1

Correspondents of the International Exchange Service—Continued.

Country.	Correspondents. Libraries.	Individuals.	Total.
AFRICA—continued.			
Gambia	....	2	2
Gold Coast	....	2	2
Gorée-Dakar	....	1	1
Lagos	2	....	2
Liberia	2	5	7
Lorenzo Marques	....	2	2
Madagascar	1	6	7
Madeira	3	3	6
Mauritius	11	6	17
Morocco	....	10	10
Mozambique	....	1	1
Natal	7	11	18
Orange Free State	....	1	1
Réunion	1	....	1
Saint Helena	2	2	4
Senegal	....	2	2
Sierra Leone	1	2	3
South African Republic	11	7	18
Tunis	6	4	10
Zanzibar	....	5	5
AMERICA (NORTH).			
Canada	309	365	674
Central America:			
British Honduras	4	6	10
Costa Rica	23	27	50
Guatemala	37	47	84
Honduras	8	19	27
Nicaragua	10	19	29
Salvador	11	8	19
Greenland	2	....	2
Mexico	124	105	229
Newfoundland	10	6	16
St. Pierre-Miquelon	1	2	3
United States	2,533	4,382	6,915
West Indies:			
Anguilla	....	1	1
Antigua	4	4	8
Bahamas	2	10	12
Barbados	6	9	15
Bermuda	1	11	12
Buen Ayre	....	1	1
Cuba	34	78	112
Curaçao	....	3	3
Dominica	1	6	7
Grenada	1	5	6
Guadeloupe	2	4	6
Haiti	5	15	20
Jamaica	10	27	37
Martinique	1	4	5
Montserrat	....	2	2
Nevis	....	1	1
AMERICA (NORTH)—cont'd.			
West Indies—Continued.			
Porto Rico	....	14	14
St. Bartholomew	....	2	2
St. Christopher	1	3	4
St. Croix	1	2	3
St. Eustatius	....	1	1
St. Martin	....	2	2
St. Lucia	1	3	4
St. Thomas	....	3	3
St. Vincent	1	2	3
Santo Domingo	2	10	12
Tobago	....	1	1
Trinidad	9	7	16
Turks Islands	1	5	6
AMERICA (SOUTH).			
Argentina	100	90	190
Bolivia	13	4	17
Brazil	97	107	204
British Guiana	14	10	24
Chile	61	64	125
Colombia	27	39	66
Dutch Guiana	2	2	4
Ecuador	13	14	27
Falkland Islands	....	5	5
French Guiaua	....	2	2
Paraguay	10	6	16
Peru	25	49	74
Uruguay	34	22	56
Venezuela	26	37	63
ASIA.			
Arabia	....	7	7
British Burmah	6	....	6
Celebes	....	1	1
Ceylon	20	8	28
China	31	64	95
Cochin China	4	2	6
Corea	1	7	8
Cyprus	2	4	6
French East Indies	1	1	2
Kongkong	5	7	12
India	167	164	331
Japan	89	194	283
Java	12	20	32
New Guinea	....	1	1
North Borneo	....	1	1
Persia	2	7	9
Phillipine Islands	6	9	15
Portuguese India	1	....	1
Siam	4	9	13
Straits Settlements	10	10	20
Sumatra	....	2	2

Correspondents of the International Exchange Service—Continued.

Country.	Correspondents.			Country.	Correspondents.		
	Libraries.	Individuals.	Total.		Libraries.	Individuals.	Total.
AUSTRALASIA.				EUROPE—continued.			
New South Wales	61	87	148	Malta	8	10	18
New Zealand	62	68	130	Netherlands	158	192	350
Queensland	29	36	65	Norway	108	85	193
South Australia	34	49	83	Portugal	86	62	148
Tasmania	15	12	27	Roumania	29	34	63
Victoria	85	96	181	Russia	400	532	932
Western Australia	11	13	24	Servia	15	7	22
EUROPE.				Spain	137	139	276
				Sweden	151	201	352
Austria-Hungary	603	669	1,272	Switzerland	276	399	675
Belgium	363	289	652	Turkey	26	61	87
Bulgaria	12	8	20	POLYNESIA.			
Denmark	90	131	221				
France	1,430	1,371	2,801	Fiji Islands	1	3	4
Germany	2,066	2,079	4,145	Hawaiian Islands	16	49	65
Gibraltar	....	4	4	New Caledonia	....	1	1
Great Britain	1,587	3,057	4,644	New Hebrides	1	....	1
Greece	34	30	64	Tahiti	....	2	2
Iceland	16	8	24	International	32	....	32
Italy	677	563	1,240	Total	12,693	16,760	29,458
Luxemburg	8	1	9				

INTERNATIONAL EXCHANGE OF OFFICIAL DOCUMENTS.

The following table shows the number of packages forwarded and received during the year by the Departments and Bureaus of the United States Government through the Smithsonian Institution. Those packages credited to the Library of Congress were sent in conformity to the act of Congress of 1867, which provided fifty sets of all official publications for national depositories abroad, while the publications credited to other branches of the Government were contributed direct.

Statement of Government exchanges during the year 1897–98.

Name of bureau.	Packages.		Name of bureau.	Packages.	
	Received for.	Sent by.		Received for.	Sent by.
American Historical Association	7	37	Bureau of Statistics, State Department	1	....
Bureau of American Ethnology	223	1,483	Bureau of Statistics, Treasury Department	23	3
Bureau of American Republics	4	14	Bureau of Steam Engineering, Navy Department	1	....
Bureau of Education	77	4	Census Office	8	....
Bureau of Equipment, Navy Department	1	....	Civil Service Commission	5	....
Bureau of Medicine and Surgery	7	....	Coast and Geodetic Survey	92	247
Bureau of the Mint	1	....	Commissioners of the District of Columbia	2	11
Bureau of Navigation	2	....	Comptroller of the Currency	1	....
Bureau of Ordnance, Navy Department	1	....	Court of Claims	....	2

Statement of Government exchanges during the year 1897–98—Continued.

Name of bureau.	Packages. Received for.	Packages. Sent by.	Name of bureau.	Packages. Received for.	Packages. Sent by.
Department of Agriculture	263	14	Nautical Almanac Office	20	108
Department of the Interior	18	....	Naval Observatory	125	9
Department of Labor	17	....	Navy Department	2	500
Department of State	20	....	Office of the Chief of Engineers, U. S. A	29	31
Entomological Commission	9	....	Office of Experiment Stations, Department of Agriculture	287	....
Fish Commission	77	403	Office of Indian Affairs	7	....
General Land Office	4	....	Patent Office	59	3,716
Geological Survey	480	3,147	President of the United States	1	....
Hydrographic Office	78	....	Signal Office	28	....
Interstate Commerce Commission	13	34	Smithsonian Institution	1,861	4,278
Library of Congress	2,192	13,500	Superintendent of Documents	....	9
Life-Saving Service	1	....	Surgeon-General's Office, U.S.A	164	342
Light-House Board	3	1	Treasury Department	5	1
Marine-Hospital Service	7	98	War Department	7	....
National Academy of Sciences	93	36	Weather Bureau	54	714
National Board of Health	2	....	Total	6,612	32,172
National Museum	223	3,430			
National Zoological Park	7	....			

RELATIVE INTERCHANGE OF PUBLICATIONS BETWEEN THE UNITED STATES AND FOREIGN COUNTRIES.

In continuation of the system mentioned in the report for the year ending June 30, 1897, a comparative statement is appended showing the number of exchange parcels distributed between this and other countries during the past two years. It will be observed that eleven countries participated in the service last year which were not represented in 1897.

Comparative statement of packages received for transmission through the International Exchange Service during the fiscal years ending June 30, 1897, and June 30, 1898.

Country.	1897. Packages. For.	1897. Packages. From.	1898. Packages. For.	1898. Packages. From.
Algeria	68	49	85	94
Angola	1	....	....	....
Argentina	1,214	378	1,302	343
Austria-Hungary	2,887	1,636	3,076	1,348
Azores	15	....	4	....
Bahamas	14	....	20	....
Barbados	5	....	6	4
Belgium	1,412	393	1,634	1,018
Bermudas	7	....	5	....
Bolivia	10	34	22	....
Borneo	3	....	....	....
Brazil	820	778	836	991
British America	1,576	856	1,951	1,130
British Burmah	6	....	1	....
British Colonies *a*	62	....	42	....

a Other than those specifically mentioned.

Comparative statement of packages received for transmission through the International Exchange Service, etc.—Continued.

Country.	1897. Packages. For.	1897. Packages. From.	1898. Packages. For.	1898. Packages. From.
British Guiana	24	2	31	2
British Honduras	....	....	9	....
Bulgaria	....	....	30	1
Canary Islands	....	....	1	....
Cape Colony	172	4	175	5
Chile	598	17	670	121
China	114	108	151	165
Colombia	265	....	351	....
Costa Rica	165	613	179	597
Cuba	128	....	80	....
Denmark	652	215	827	170
Dutch Guiana	8	....	8	....
Ecuador	30	....	56	....
Egypt	69	....	105	....
Fiji Islands	....	....	2	....
France	5,877	1,915	6,251	2,430
Friendly Islands	3	....	23	....
Germany	10,506	4,988	10,089	4,510
Gold Coast	....	....	13	....
Great Britain and Ireland	10,092	8,145	10,271	5,204
Greece	105	30	120	....
Greenland	3	....	5	....
Guadeloupe	5	....	1	....
Guatemala	57	....	57	....
Guinea	1	....	1	....
Haiti	332	....	282	....
Hawaiian Islands	58	....	70	....
Honduras	8	....	11	34
Iceland	48	....	59	....
India	817	182	1,011	77
Italy	2,763	1,393	3,479	1,079
Jamaica	49	....	63	....
Japan	805	12	841	18
Java	113	113	131	124
Korea	2	....	2	....
Leeward Islands	....	....	2	....
Liberia	29	....	37	....
Luxemburg	....	....	43	1
Madagascar	5	....	6	....
Madeira	1	....	3	....
Malta	40	....	30	....
Mauritius	43	....	44	....
Mexico	1,108	389	1,221	57
Natal	....	....	13	2
Netherlands	1,194	544	1,191	421
New Guinea	....	1	....	....
New Hebrides	....	....	1	....
New South Wales	712	196	860	100
New Zealand	433	4	550	8
Nicaragua	19	....	44	....

Comparative statement of packages received for transmission through the International Exchange Service, etc.—Continued.

Country.	1897. Packages. For.	1897. Packages. From.	1898. Packages. For.	1898. Packages. From.
Norway	755	46	861	309
Paraguay	12	253	21	....
Persia	3	....	2	....
Peru	307	92	380	50
Philippine Islands	49	....	44	....
Portugal	526	227	749	843
Queensland	466	....	544	....
Roumania	48	63	53	1
Russia	2,246	1,862	2,053	1,247
Saint Helena	7	....	6	....
Samoa	....	....	1	....
Santo Domingo	2	....	1	....
San Salvador	43	....	44	....
Servia	16	....	50	2
Siam	13	....	38	....
South African Republic	26	1	33	2
South Australia	358	3	460	36
Spain	646	....	698	....
Straits Settlements	24	....	35	....
Sumatra	....	....	1	....
Syria	5	....	6	....
Sweden	1,161	612	2,754	392
Switzerland	1,570	827	1,720	838
Tasmania	219	....	354	....
Trinidad	39	....	42	....
Tunis	2	....	18	....
Turkey	293	....	349	3
Turks Island	1	....	4	....
United States	23,619	52,185	21.057	58,640
Uruguay	317	184	419	84
Venezuela	272	....	348	....
Victoria	652	119	751	87
West Australia	238	....	307	....
Zanzibar	1	....	1	....

EFFICIENCY OF THE SERVICE.

So far as the appropriations permitted, the facilities for rapid transportation of exchanges have been improved, but until more ample funds shall be made available it will be necessary to continue to rely largely upon the liberality of the several trans-oceanic steamship lines which have for so long a time been giving free transportation.

Through the courtesy of the American Board of Commissioners for Foreign Missions and the Board of Foreign Missions of the Presbyterian Church in the United States, packages of miscellaneous publications are forwarded to Turkey, but the transmission of United States Government documents has not been revived since its discontinuance in 1896, as explained in my last report. The extensive demand for scientific publications from this country is expected to result in the near future in the establishment of an exchange bureau in Japan. Until that is done, or at least until some responsible institution is prepared to undertake the distribution of exchanges intended for that country, the forwarding of all miscellaneous exchanges must remain in abeyance. Negotiations are now pending, through the intervention of the United States minister to Greece, for the reopening of exchange relations with the National Library at Athens, which have now been suspended for several years, and it is anticipated that satisfactory arrangements will soon be completed.

With the exceptions mentioned above and the interruption of intercourse with Spain and her colonies on account of the war, exchange relations throughout the world are more completely established than ever before, and it is believed that the few connections still remaining to perfect the system will be made at no distant time.

For many years all exchanges for Austria-Hungary, Switzerland, and the Balkan countries have been forwarded, in conjunction with German exchanges, through the agency of the Institution at Leipzig. This indirect system of transmission was inaugurated at a time when the total amount of the shipments to those countries was relatively small and the practice has been allowed to continue in view of the zealous and efficient manner in which Dr. Felix Flügel has performed his duties as agent. The rapid increase in recent years in the amount of work at this agency has made the burden too heavy, however, especially when taking into consideration the formalities necessary for clearing and transporting packages between Germany and the other countries that participate in this arrangement, and rendered it necessary to provide for more direct means of communication. Thus it was found desirable, as suggested in my last report, to establish agencies in Austria and Hungary, to which shipments could be made direct. With this end in view the chief clerk of the international exchanges was instructed to visit those countries late in the summer of 1897, and upon his return to recommend the designation of suitable agents. As a result Dr. Joseph von Körösy, director of the Statistical Bureau of Budapest, and the Imperial Royal Central Statistical Commission of Vienna were appointed agents of the service, thus eliminating the entire territory of Austria-Hungary from the jurisdiction of the overburdened agency at Leipzig. In addition to securing these new agents, the representatives of the exchange service at Leipzig, Brussels, Paris, and London were visited and much valuable information obtained, which has already been productive of many improvements in the service.

Messrs. William Wesley & Son and Dr. Felix Flügel, the agents of the exchange service at London and Leipzig, respectively, have been so long identified with the Institution that no comment as to their efficiency or faithful service is necessary. Great credit is due the clerical force of the exchange service. While the work is at times burdensome and requires extraordinary effort, the force has always been found equal to any emergency.

The following list represents the names of companies and other mediums of transportation that have aided the Institution during the past year in the transmission and distribution of exchanges, either without compensation or at minimum rates, some of which have extended equal courtesies to the Institution for many years:

American Board of Commissioners for Foreign Missions, Boston, Mass.
Amundsen, L. O. G., acting consul of Denmark, New York.
Atlas Line of Mail Steamers (Pim, Forwood & Kellock, agents), New York.
Board of Foreign Missions of the Presbyterian Church, New York.
Calderon, Climaco, consul-general of Colombia, New York.
Compagnie Générale Transatlantique, New York.
Cunard Steamship Company (Vernon H. Brown & Co., agents), New York.
Eddy, Thomas A., consul of Uruguay, New York.
Grace, W. R., & Co., New York.
Hamburg-American Line, New York.
Hensel, Bruckmann & Lorbacher, New York.
Holland-America Line, New York.
Mediterranean and New York Steamship Company (Phelps Bros. & Co., agents), New York.
Murguiondo, Prudencio de, consul-general of Uruguay, Baltimore, Md.

Navarro, Juan N., consul-general of Mexico, New York.

North German Lloyd Steamship Company (Oelrichs & Co., New York, and A. Schumacher & Co., Baltimore, agents).

Panama Railroad Steamship Line (W. J. Herron, agent), New York.

Peraza, N. Bolet, consul-general of San Salvador, New York.

Perry, Edward, & Co., New York.

Red "D" Line of Steamships (Boulton, Bliss & Dallett, general managers), New York.

Red Star Line (International Navigation Company, agents), New York.

Röhl, Carlos, consul-general of Argentina, New York.

Santos, Alejandro, consul-general of Bolivia, New York.

Stewart, John, consul-general of Paraguay, Washington, D. C.

Taveira, Luis Augusto de M. P. de A., consul-general of Portugal, New York.

Woxen, Karl G. M., consul of Sweden and Norway, New York.

Yela, Julius, chancellor, consulate of Guatemala, New York.

The following is a list of the Smithsonian correspondents acting as distributing agents, or receiving publications for transmission to the United States:

Algeria. (*See* France.)

Argentina: Museo Nacional, Buenos Ayres.

Austria: K. K. Statistische Central-Commission, Vienna.

Brazil: Bibliotheca Nacional, Rio de Janeiro.

Belgium: Commission des Échanges Internationaux, Rue du Musée, 5, Brussels.

Bolivia: University, Chuquisaca.

British America: Packages sent by mail.

British Colonies: Crown Agents for the Colonies, London, England.

British Guiana. (*See* British Colonies.)

Cape Colony: Colonial Secretary, Cape Town.

Chile: Universidad de Chile, Santiago.

China: Zi-ka-wei Observatory, Shanghai.

Colombia: Biblioteca Nacional, Bogotá.

Costa Rica: Oficina de Depósito, Reparto y Canje Internacional, San José.

Denmark: Kongelige Danske Videnskabernes Selskab, Copenhagen.

Dutch Guiana: Surinaamsche Koloniale Bibliotheek, Paramaribo.

East India: Director General of Stores, India Office, London, England.

Ecuador: Observatorio del Colegio Nacional, Quito.

Egypt: Société Khédiviale de Géographie, Cairo.

France: Bureau Français des Échanges Internationaux, 110 Rue de Grenelle, Paris.

Germany: Dr. Felix Flügel, Schenkendorf Strasse, 9, Leipzig.

Great Britain and Ireland: William Wesley & Son, 28 Essex street, Strand, London

Guadeloupe. (*See* France.)

Guatemala: Instituto Nacional de Guatemala, Guatemala.

Haiti: Secrétaire d'Etat des Relations Extérieures, Port au Prince.

Honduras: Biblioteca Nacional, Tegucigalpa.

Hungary: Dr. Joseph von Körösy, "Redonte," Budapest.

Iceland. (*See* Denmark.)

Italy: Biblioteca Nazionale Vittorio Emanuele, Rome.

Japan: Minister of Foreign Affairs, Tokio.

Java. (*See* Netherlands.)

Liberia: Liberia College, Monrovia.

Madeira. (*See* Portugal.)

Malta. (*See* British Colonies.)

Mauritius. (*See* British Colonies.)

Mexico: Packages sent by mail.

Mozambique. (*See* Portugal.)

Natal: Agent-General for Natal, London, England.

Netherlands: Bureau Scientifique Central Néerlandais, Den Helder

Newfoundland: Transmissions sent direct by mail.

New South Wales: Government Board for International Exchanges, Free Public Library, Sydney.
New Zealand: Colonial Museum, Wellington.
Nicaragua: Ministerio de Relaciones Exteriores, Managua.
Norway: Kongelige Norske Frederiks Universitet, Christiania.
Paraguay: Government, Asunçion.
Peru: Biblioteca Nacional, Lima.
Philippine Islands. (*See* Spain.)
Polynesia: Department of Foreign Affairs, Honolulu.
Portugal: Biblioteca Nacional, Lisbon.
Queensland: Registrar-General of Queensland, Brisbane.
Roumania. (*See* Germany.)
Russia: Commission Russe des Échanges Internationaux, Bibliothèque Impériale Publique, St. Petersburg.
Saint Helena. (*See* British Colonies.)
San Salvador: Museo Nacional, San Salvador.
Servia. (*See* Germany.)
Siam: Board of Foreign Missions of the Presbyterian Church, New York.
South Australia: Astronomical Observatory, Adelaide.
Spain: Real Academia de Ciencias, Madrid.
Sweden: Kongliga Svenska Vetenskaps Akademien, Stockholm.
Switzerland: Bibliothèque Fédérale, Bern.
Syria: Board of Foreign Missions of the Presbyterian Church, New York.
Tasmania: Royal Society of Tasmania, Hobarton.
Turkey: American Board of Commissioners for Foreign Missions, Boston, Mass.
Uruguay: Oficina de Depósito, Reparto y Canje Internacional, Montevideo.
Venezuela: Museo Nacional, Carácas.
Victoria: Public Library, Museums, and National Gallery, Melbourne.
Western Australia: Agent-General, London, England.

Transmissions of exchanges to foreign countries.

Country.	Date of transmission.
Argentina	July 20, September 23, December 18, 1897; February 11, June 10, 1898.
Austria	July 2, 14, 26, 28, August 10, 14, September 9, 16, October 11, 23, November 1, 1897.
Belgium	July 13, 24, September 11, 15, October 19, November 17, 27, 1897; January 5, 27, March 4, May 16, 25, 1898.
Bolivia	September 23, 1897; June 10, 1898.
Brazil	July 20, September 23, December 18, 1897; February 11, June 10, 1898.
British colonies	August 6, September 18, December 11, 1897; March 9, May 24, June 28, 1898.
Cape Colony	September 27, December 11, 1897; June 15, 1898.
China	January 3, June 29, 1898.
Chile	July 20, September 23, December 18, 1897; February 11, June 10, 1898.
Colombia	July 20, September 23, 1897; June 10, 1898.
Costa Rica	September 24, December 22, 1897; June 13, 1898.
Cuba	February 23, 1898.
Denmark	August 4, September 14, November 16, 30, 1897; January 8, March 12. May 18, June 21, 1898.
East India	August 6, September 27, December 8, 1897; February 15, May 24, June 28, 1898.
Egypt	September 27, December 11, 1897; June 15, 1898.
France and colonies	July 8, 28, August 4, 14, September 16, 18, October 15, 25, November 5, 20, 23, 30, December 2, 13, 1897; January 4, 28, February 28, March 16, April 29, June 1, 18, 25, 1898.

Transmissions of exchanges to foreign countries—Continued.

Country.	Date of transmission.
Germany	July 2, 14, 26, August 10, 14, September 9, 16, October 11, 23, November 1, 15, 24, 30, December 2, 15, 1897; January 3, 24, February 7, 28, March 14, 24, May 3, June 2, 18, 27, 1898.
Great Britain and Ireland	July 6, 16, 31, August 6, 14, September 10, 18, October 13, 20, 29, November 9, 22, 26, 30, December 2, 8, 11, 28, 1897; January 13, 21, 24, February 5, 15, 25, March 9, April 25, May 16, 24, June 4, 18, 28, 1898.
Guatemala	September 24, 1897; June 13, 1898.
Honduras	June 13, 1898.
Hungary	February 2, June 17, 1898.
Italy	July 9, 31, August 16, September 11, 27, October 16, November 8, 27, December 1, 2, 1897; January 7, February 4, March 1, May 9, June 24, 1898.
Japan	December 6, 1897; June 16, 1898.
Liberia	December 11, 1897; June 15, 1898.
Mexico	(By registered mail.)
Natal	December 11, 1897; June 15, 1898.
New South Wales	July 23, September 27, December 24, 1897; May 24, 1898.
Netherlands	July 9, August 3, September 13, November 17, 27, December 1, 1897; January 10, March 5, May 12, June 21, 1898.
New Zealand	July 23, September 27, December 24, 1897; May 24, 1898.
Nicaragua	September 24, December 22, 1897; June 13, 1898.
Norway	September 13, November 27, December 1, 1897; January 11, May 19, June 17, 1898.
Peru	July 20, September 23, December 18, 1897; June 10, 1898.
Polynesia	July 23, December 24, 1897; May 24, 1898.
Portugal	September 14, November 30, 1897; January 12, May 1, 1898.
Queensland	July 23, September 27, November 9, December 24, 1897; January 24, March 9, May 4, June 28, 1898.
Roumania	(Included in Germany.)
Russia	July 10, August 2, September 13, 15, October 18, November 19, 27, December 1, 2, 1897; January 10, February 3, March 3, May 6, June 21, 1898.
San Salvador	September 24, 1897; June 23, 1898.
Servia	(Included in Germany.)
South Australia	July 23, September 27, December 24, 1897; May 24, 1898.
Spain	August 17, September 14, November 20, 30, 1897; February 10, 1898.
Sweden	July 10, August 2, September 15, October 18, November 19, 27, December 1, 2, 1897; January 10, February 3, March 3, May 6, June 28, 1898.
Switzerland	August 2, 17, September 21, October 27, November 27, December 1, 1897; January 8, March 7, May 10, June 21, 1898.
Tasmania	December 24, 1897.
Turkey	January 12, 1898.
Uruguay	September 23, December 18, 1897: February 11, June 10, 1898.
Venezuela	July 20, September 23, December 18, 1897; June 10, 1898.
Victoria	July 23, September 27, December 24, 1897; May 24, 1898.
Western Australia	July 23, December 24, 1897; May 24, 1898.

The distribution of exchanges to foreign countries was made in 1,140 cases, representing 219 transmissions, as follows:

Argentina	24	Brazil	15
Austria	61	British America *a*	
Belgium	37	British Colonies	11
Bolivia	2	Cape Colony	6

a Packages sent by mail.

China	2	New Zealand	8
Chile	11	Nicaragua	4
Colombia	3	Norway	15
Costa Rica	5	Peru	4
Cuba	5	Polynesia	3
Denmark	16	Portugal	7
East India	14	Queensland	14
Egypt	4	Roumania *b*	
France and Colonies	129	Russia	42
Germany	182	San Salvador	2
Great Britain and Ireland	276	Servia *b*	
Guatemala	2	South Australia	6
Honduras	1	Spain	11
Hungary	11	Sweden	28
Italy	64	Switzerland	33
Japan	18	Tasmania	1
Liberia	2	Turkey	1
Mexico *a*		Uruguay	4
Natal	2	Venezuela	4
New South Wales	13	Victoria	10
Netherlands	24	Western Australia	3

a Packages sent by mail. *b* Included in transmissions to Germany.

Shipments of United States congressional publications were made on October 1, 1897, January 19, 1898, and April 19, 1898, to the governments of the following-named countries:

Argentina.	Denmark.	Netherlands.	South Australia.
Austria.	France.	New South Wales.	Spain.
Baden.	Germany.	New Zealand.	Sweden.
Bavaria.	England.	Norway.	Switzerland.
Belgium.	Haiti.	Peru.	Tasmania.
Buenos Ayres.	Hungary.	Portugal.	Uruguay.
Brazil.	India.	Prussia.	Venezuela.
Canada (Ottawa).	Italy.	Queensland.	Victoria.
Canada (Toronto).	Japan.	Russia.	Western Australia
Chile.	Mexico.	Saxony.	Württemberg.
Colombia.			

A special shipment was made to Western Australia on June 23, 1898.

Shipments to Greece and Turkey have been temporarily suspended, and the shipment of April 19 was necessarily withheld from Spain.

Recapitulation.

	Cases.
Total Government shipments	190
Total miscellaneous shipments	1,140
Total shipments	1,330
Total shipments last year	1,300
Increase over last year	30

Respectfully submitted.

RICHARD RATHBUN,
Assistant Secretary.

Mr. S. P. LANGLEY,
Secretary of the Smithsonian Institution.

Appendix IV.

REPORT OF THE SUPERINTENDENT OF THE NATIONAL ZOOLOGICAL PARK.

Sir: I have the honor to submit the report of the National Zoological Park for the year ending June 30, 1898.

In response to your request that the report shall begin with the following statements—

1. The amount, kinds, and classes of property belonging to the Park;

2. The amount of such property acquired during the twelve months covered by the report;

3. The extent and kind of improvements made in the buildings and grounds during the past year and the estimated cost;

4. The extent and character of the losses of property and the origin and causes—

I have the honor to say that at the end of this period there were in the park thirteen buildings for animals, which have cost about $50,000; six buildings for administrative purposes, costing about $9,000; fences and outdoor inclosures, costing about $20,000; machinery, tools, and implements, valued at $2,000; horses, valued at $885; office furniture, fixtures, and books, worth about $950; and nurseries of trees and shrubs, estimated at $1,000. The value of the roadways constructed in the park since its occupation by the Government is about $35,000.

The collection of living animals used for purposes of exhibition comprised 549 specimens, embracing 124 species, most of which were the property of the Government. The estimated value of the animals owned by the Government is $25,000.

There was acquired during the twelve months covered by this report property amounting to about $11,000, about $6,200 being for buildings and $2,500 for animals, including their transportation. A considerable number of animals were presented, the most valuable of these being a Virginia deer, a capuchin monkey, 2 coyotes, some cockatoos and macaws, the white and the wood ibis. The herd of bison now comprises 10 specimens, and as they seem to thrive in captivity, it is hoped that they may be indefinitely perpetuated. It will, no doubt, often be desirable to cross this herd with others in order to prevent the evil effects of too close breeding.

Twelve animals have bred in the park, producing an aggregate of 35 births. A few animals were received from the Yellowstone Park, among which were 8 specimens of the American white pelican.

A considerable improvement has been effected in the buildings by removing the group of shops and the property yard from the prominent place which they occupied to the northward of the main building. It was never intended that this should be adopted as the permanent situation of these buildings, and as the development of the park proceeded their intrusion became more and more irksome. Some considerable difficulty was experienced in properly locating the shops. It is necessary that they should be conveniently accessible, and at the same time where they do not markedly attract public attention. After carefully weighing all practicable locations, it was finally decided that the best place was one originally proposed by Mr. Olmsted, which is on the banks of Rock Creek, a few hundred yards above the Quarry Road bridge, not far from the paddocks for deer and llamas. Their situation is not very suitable for animals, and is not in public view from the main road. A long, low building was here erected to serve as a carpenter and blacksmith shop. Its cost was about $1,000.

Beaver Dam in Zoological Park.

The ground vacated upon the hill, which is one of the most desirable sites in the park for buildings, was used for the erection of a large shed suitable for herbivorous animals requiring a moderate degree of heat. This house is about 40 by 100 feet with a wing 30 by 40 feet. The small sum available made it necessary to limit the construction to bare necessities. It was therefore impossible to lay a floor or to finish the interior in any but the roughest manner. Eventually this house will be used mainly for such animals as antelopes and tropical deer. It is therefore known as the antelope house. Its cost was about $3,500.

The aquarium received from the Atlanta Exposition was partly set up in one of the abandoned sheds. About $200 was expended on this during the year. In order to obtain a suitable person for keeping this aquarium a competitive examination was held by the Civil Service Commission and the successful competitor was finally appointed. The first tanks to be established were those for fresh water. These have been fed by water from the city mains, but as this is frequently very turbid it became necessary to use an alum filter for the purpose of clearing it. This is disadvantageous, as it requires constant care and watchfulness to prevent an excess of the salt impregnating the water and injuring the fish. It is thought that a more satisfactory water supply can be obtained by sinking wells near the creek and forcing the water to the aquarium by a pump.

A new deer paddock was established during the year upon the high ground near the western entrance at a cost of $800. The cold damp exposure near the creek, where the paddocks have been situated, is found to affect the health of the animals.

Small shelters and alterations amounting to $700 were made during the year.

There was expended upon the continuation of the road along the meadow and its slopes $4,800. Repairs to existing roads amounted to about $1,000. Upon walks there was spent $650.

The seeding, planting, sodding, and improving of grounds cost in the neighborhood of $1,200.

Considerable deterioration in the buildings and inclosures of the park has occurred during the year, due in great measure to the temporary character of these structures. The elephant barn is still in a very serious condition, the floor in the principal animal house greatly needs to be wholly replaced, and the smaller buildings and cages must, many of them, soon be entirely rebuilt. The bridge over Rock Creek near the Quarry road shows signs of decay in some of its principal timbers, and will soon have to be replaced by a more permanent structure. It is estimated that this will cost about $8,500.

The losses of animals were no greater than is usual among animals kept in confinement, although several of the buildings are by no means suitable for the animals confined in them. Tropical birds and monkeys necessarily suffer when placed in buildings that are not kept at a constant temperature of at least 70°. It is hoped that houses specially adapted to these classes of animals may be erected in the park at no distant day.

I append herewith a list of the animals in the park at the close of the year; also the accessions from various sources during the year.

Animals in the National Zoological Park June 30, 1898.

Name.	Number.	Name.	Number.
MAMMALS.		MAMMALS—continued.	
American bison (*Bison americanus*)	10	American elk (*Cervus canadensis*)	13
Zebu (*Bos indicus*)	3	Virginia deer (*Cariacus virginianus*)	9
Common goat (*Capra hircus*)	10	Solid-hoofed hog (*Sus scrofa*, var. *solidungulata*)	1
Cashmere goat (*Capra hircus*)	4	Peccary (*Dicotyles tajaçu*)	2
Indian antelope (*Antilope cervicapra*)	1	Llama (*Auchenia glama*)	7
Prong-horn antelope (*Antilocapra americana*)	5	Guanaco (*Auchenia huanacos*)	1

Animals in the National Zoological Park June 30, 1898—Continued.

Name.	Number.
MAMMALS—continued.	
Indian elephant (*Elephas indicus*)	2
Lion (*Felis leo*)	8
Tiger (*Felis tigris*)	1
Leopard (*Felis pardus*)	1
Puma (*Felis concolor*)	8
Spotted lynx (*Lynx rufus maculatus*)	3
Spotted hyena (*Hyæna crocuta*)	2
Russian wolf hound	2
Stag hound	1
Mastiff	1
St. Bernard dog	2
Pointer	2
Chesapeake Bay dog	2
Bedlington terrier	1
Smooth-coated fox terrier	3
Wire-haired fox terrier	1
Brown French poodle	1
Eskimo dog	1
Gray wolf (*Canis lupus grisco-albus*)	5
Black wolf (*Canis lupus griseo-albus*)	2
Coyote (*Canis latrans*)	6
Red fox (*Vulpes pennsylvanicus*)	4
Swift fox (*Vulpes velox*)	2
Gray fox (*Urocyon cinereo-argenteus*)	3
Mongoose (*Herpestes mungo*)	1
Tayra (*Galictis barbara*)	1
North American otter (*Lutra hudsonica*)	2
American badger (*Taxidea americana*)	4
Kinkajou (*Cercoleptes caudivolvulus*)	1
Gray coati-mundi (*Nasua narica*)	2
Cacomistle (*Bassariscus astuta*)	1
Raccoon (*Procyon lotor*)	30
Black bear (*Ursus americanus*)	4
Cinnamon bear (*Ursus americanus*)	2
Grizzly bear (*Ursus horribilis*)	2
California sea lion (*Zalophus californianus*)	6
Harbor seal (*Phoca vitulina*)	1
Macaque monkey (*Macacus cynomolgus*)	4
Bonnet monkey (*Macacus sinicus*)	1
Rhesus monkey (*Macacus rhesus*)	1
Albino rat (*Mus rattus*)	10
American beaver (*Castor fiber*)	6
Woodchuck (*Arctomys monax*)	3
Prairie dog (*Cynomys ludovicianus*)	3
Red-bellied squirrel (*Sciurus aureogaster*)	1
Fox squirrel (*Sciurus niger*)	1
Gray squirrel (*Sciurus carolinensis*)	19
Crested porcupine (*Hystrix cristata*)	4
Canada porcupine (*Erethizon dorsatus*)	6
Crested agouti (*Dasyprocta cristata*)	3
Hairy-rumped agouti (*Dasyprocta prymnolopha*)	2
Mexican agouti (*Dasyprocta mexicana*)	2
Azara's agouti (*Dasyprocta azaræ*)	2
Guinea pig (*Cavia porcellus*)	16
Northern varying hare (*Lepus americanus*)	3
Rocky Mountain varying hare (*Lepus americanus bairdii*)	1
English rabbit (*Lepus cuniculus*)	16
Angora rabbit (*Lepus cuniculus*)	1
Six-banded armadillo (*Dasypus sexcinctus*)	1
Peba armadillo (*Tatusia novemcincta*)	6
Gray kangaroo (*Macropus* sp.)	2
Brush-tailed rock kangaroo (*Petrogale penicillata*)	1
BIRDS.	
Clark's nutcracker (*Nucifraga columbiana*)	4
Sulphur-crested cockatoo (*Cacatua galerita*)	2
Leadbeater's cockatoo (*Cacatua leadbeateri*)	3
Bare-eyed cockatoo (*Cacatua gymnopis*)	1
Yellow and blue macaw (*Ara ararauna*)	2
Red and yellow and blue macaw (*Ara macao*)	2
Green parrakeet (*Conurus* sp.)	1
Carolina paroquet (*Conurus carolinensis*)	3
Yellow-naped amazon (*Amazona auropalliata*)	1
Levaillant's amazon (*Amazona levaillanti*)	1
Gray parrot (*Psittacus erithacus*)	4
Great horned owl (*Bubo virginianus*)	9
Barred owl (*Syrnium nebulosum*)	3
Bald eagle (*Haliæëtus leucocephalus*)	13
Red-tailed hawk (*Buteo borealis*)	1
Turkey vulture (*Cathartes aura*)	2
Ring dove (*Columba palumbus*)	9
Chachalaca (*Ortalis vetula maccallii*)	6
Lesser razor-billed curassow (*Mitua tomentosa*)	1
Peafowl (*Pavo cristatus*)	21
Sandhill crane (*Grus mexicana*)	1
Whooping crane (*Grus americana*)	1
Great blue heron (*Ardea herodias*)	2
Black-crowned night heron (*Nycticorax nycticorax nævius*)	4
Wood ibis (*Tantalus loculator*)	3
Whistling swan (*Olor columbianus*)	
Mute swan (*Cygnus gibbus*)	8
Brant (*Branta bernicla*)	3
Canada goose (*Branta canadensis*)	2
Hutchins' goose (*Branta canadensis hutchinsii*)	1
Chinese goose (*Anser cygnoides*)	3
Toulouse goose (*Anser* sp.)	1
Mandarin duck (*Dendronessa galericulata*)	2
Pekin duck (*Anas* sp.)	7

Swan's Nest in Zoological Park.

Animals in the National Zoological Park June 30, 1898—Continued.

Name.	Number.	Name.	Number.
BIRDS—continued.		REPTILES—continued.	
Common duck (*Anas boschas*)	7	Diamond rattlesnake (*Crotalus adamanteus*)	4
American white pelican (*Pelecanus erythrorhynchos*)	8	Copperhead (*Ancistrodon contortrix*)	2
American herring gull (*Larus argentatus smithsonianus*)	1	Water moccasin (*Ancistrodon piscivorus*)	5
African ostrich (*Struthio camelus*)	1	Python (*Python* sp.)	2
REPTILES.		Boa (*Boa constrictor*)	3
Alligator (*Alligator mississippiensis*)	25	Anaconda (*Eunectes murinus*)	1
Snapping turtle (*Chelydra serpentina*)	1	Scarlet snake (*Cemaphora coccinea*)	1
Painted turtle (*Chrysemys picta*)	6	Bull snake (*Pituophis sayi*)	2
Musk turtle (*Aromochelys odorata*)	2	Pine snake (*Pituophis melanoleucus*)	4
Mud turtle (*Cinosternum pennsylvanicum*)	5	Milk snake (*Ophibolus doliatus*)	4
Terrapin (*Pseudemys* sp.)	1	King snake (*Ophibolus getulus*)	5
Gopher turtle (*Xerobates polyphemus*)	1	Black snake (*Bascanium constrictor*)	2
Iguana (*Iguana* sp.)	3	Mountain black snake (*Coluber obsoletus*)	3
Gila monster (*Heloderma suspectum*)	5	Garter snake (*Eutænia sirtalis*)	4
		Water snake (*Natrix sipedon*)	5
		Hog-nosed snake (*Heterodon platyrhinus*)	1
		Gopher snake (*Spilotes corais couperii*)	5

	Indigenous.	Foreign.	Domesticated.	Total.
Mammals	177	40	85	302
Birds	68	21	56	145
Reptiles	93	9	....	102
Total	338	70	141	549

List of accessions for fiscal year ending June 30, 1898.

ANIMALS PRESENTED.

Name.	Donor.	Number of specimens.
Capuchin	J. O'Connor, Washington, D. C	1
Wild cat	J. A. August, jr., Pine Hill, Ky	1
Coyote	Morris Bartlett, Hornbrook, Pa	2
Red fox	S. Ross, Washington, D. C	1
Do	W. W. Bride, Washington, D. C	1
Gray fox	A. M. Woltz, Washington, D. C	1
Do	H. T. Harvey, Washington, D. C	1
Do	A. M. Nicholson, Orlando, Fla	1
Raccoon	H. Monroe, Washington, D. C	2
Do	Dr. W. F. Hutchinson, Winchester, Va	1
Do	Miss Keightly Timberlake, Charlestown, W. Va	1
Do	Metropolitan Club, Washington, D. C	1
Do	A. M. Nicholson, Orlando, Fla	4
Common goat	W. T. Lynch, Washington, D. C	1
Virginia deer	A. M. Green, Anacostia, D. C	1
Prairie dog	Mrs. W. W. Anderson, Washington, D. C	1
Northern varying hare	A. F. Chapman, Bethel, Me	4
English rabbit	Westley Peckham, Washington, D. C	1
Do	Miss Sallie Lacy, Washington, D. C	1
Do	Leo Busch, Washington, D. C	1
Canada porcupine	A. F. Chapman, Bethel, Me	6

List of accessions for fiscal year ending June 30, 1898—Continued.

ANIMALS PRESENTED—Continued.

Name.	Donor.	Number of specimens.
Opossum	John T. Detwiler, New Smyrna, Fla	1
Turkey vulture	Wm. Palmer, Washington, D. C	1
Golden eagle	Hartell & Conway, Cumberland, Md	1
Red-tailed hawk	Dr. J. W. Kales, Franklinville, N. Y	1
American osprey	H. H. Miller and B. T. Roodhouse, Washington, D. C	1
Great horned owl	H. E. Wyatt, Baltimore, Md	2
Do	A. M. Nicholson, Orlando, Fla	1
Do	J. H. Hamill, Washington, D. C	1
Do	Miss Ethel Woodward, Knoxville, Tenn	2
Barred owl	E. T. McKinney, Washington, D. C	2
Screech owl	J. L. Hutchinson, Washington, D. C	1
Amazona	Mrs. M. A. Blake, Washington, D. C	1
Gray-breasted parrakeet	W. H. Huntington, Washington, D. C	1
Leadbeater's cockatoo	Mrs. N. F. Keefe, Syracuse, N. Y	2
Yellow and blue macaw	P. M. DeLeon, consul-general at Guayaquil, Ecuador	1
White ibis	A. M. Nicholson, Orlando, Fla	1
Wood ibis	do	5
Black-crowned night heron	Perry, Washington, D. C	4
Snake bird	A. M. Nicholson, Orlando, Fla	1
Florida cormorant	do	1
Loon	W. Smith, Washington, D. C	1
Alligator	Francis Pretrola, Washington, D. C	1
Do	G. F. Seifert, Baltimore, Md	1
Do	Mrs. Cranford, Washington, D. C	3
Do	Metropolitan Club, Washington, D. C	2
Do	Archie Dorst, Washington, D. C	2
Do	Mrs. Mackay-Smith, Washington, D. C	1
Do	Lawrence Gibson, Washington, D. C	1
Do	H. C. Banoult, Company A, First Regiment District of Columbia Volunteers, Tampa, Fla.	1
Do	W. B. Curtis, Washington, D. C	1
Chameleon	Mrs. Cranford, Washington, D. C	5
Horned lizard	W. Stewart, Washington, D. C	1
Gila monster	W. W. Wilson, Casagrande, Ariz	1
Prairie rattlesnake	L. W. Purinton, Banner, Kans	3
Copperhead snake	B. Saers, Washington, D. C	1
Scarlet snake	J. Y. Detwiler, New Smyrna, Fla	1
Le Conte's snake	E. Meyenberg, Pecos City, Tex	1
Python	G. P. Eustis, Washington, D. C	1
Bull snake	L. W. Purinton, Banner, Kans	5
Black Snake	A. M. Nicholson, Orlando, Fla	3
Mountain black snake	Victor Mindeleff, Washington, D. C	1
Hog-nosed snake	A. M. Nicholson, Orlando, Fla	1

ANIMALS LENT.

Barbary ape	C. Cannon, Washington, D. C	1
White-throated capuchin	J. L. Hoge, Neill, Va	1
Mongoose	John Paine, Washington, D. C	1
Common goat	E. S. Schmid, Washington, D. C	4
Do	C. W. Neale, Washington, D. C	1
Peafowl	E. S. Schmid, Washington, D. C	5
Alligator	Capt. Thos. Cruse, U. S. A., Washington, D. C	2

List of accessions for fiscal year ending June 30, 1898—Continued.

ANIMALS RECEIVED IN EXCHANGE.

Name.	Donor.	Number of specimens.
Spider monkey	E. S. Schmid, Washington, D. C	1
Bald eagle	.....do	1

Animals Purchased.

North American otter (*Lutra hudsonica*)	2
California sea lion (*Zalophus californianus*)	3
American bison (*Bison americanus*)	3
Carolina parrakeet (*Conurus carolinensis*)	3
Sharp-nosed crocodile (*Crocodilus americanus*)	2
Iguana (*Iguana* sp.)	3
Banded basilisk (*Basiliscus vittatus*)	2
Diamond rattlesnake (*Crotalus adamanteus*)	4
Banded rattlesnake (*Crotalus horridus*)	1
Water moccasin (*Ancistrodon piscivorus*)	5
Pine snake (*Pituophis melanoleucus*)	4
King snake (*Ophibolus getulus*)	5
Gopher snake (*Spilotes corais couperii*)	2

Animals born in the National Zoological Park.

Lion (*Felis leo*)	4
Puma (*Felis concolor*)	7
American bison (*Bison americanus*)	1
Zebu (*Bos indicus*)	1
Cashmere goat (*Capra hircus*)	1
American elk (*Cervus canadensis*)	4
Virginia deer (*Cariacus virginianus*)	2
Llama (*Auchenia glama*)	2
Crested porcupine (*Hystrix cristata*)	1
Ring dove (*Columba palumbus*)	3
Mute swan (*Cygnus gibbus*)	6
Water moccasin (*Ancistrodon piscivorus*)	6

Animals captured in the National Zoological Park.

Raccoon (*Procyon lotor*)	2

Animals received from Yellowstone National Park.

American magpie (*Pica pica hudsonica*)	5
Rocky Mountain jay (*Perisoreus canadensis capitalis*)	2
Hutchins goose (*Branta canadensis hutchinsii*)	1
American white pelican (*Pelecanus erythrorhynchos*)	8

SUMMARY OF ACCESSIONS.

Animals presented	103
Animals purchased	39
Animals lent	15
Animals received in exchange	2
Animals born in the Zoological Park	38

Animals captured in the Zoological Park		2
Animals received from the Yellowstone National Park		16
Total		215
Number of specimens on hand June 30, 1897		567
Accessions during the year ending June 30, 1898		215
Total		782
Deduct—		
Deaths	184	
Animals escaped or liberated	7	
Animals exchanged	15	
Animals returned to owners	27	
		233
Animals on hand June 30, 1898		549

Respectfully submitted.

FRANK BAKER, *Superintendent.*

Mr. S. P. LANGLEY,
Secretary of the Smithsonian Institution.

Appendix V.

REPORT ON THE WORK OF THE ASTROPHYSICAL OBSERVATORY FOR THE YEAR ENDING JUNE 30, 1898.

Sir: I have the honor to submit the report of the Astrophysical Observatory for the year ending June 30, 1898.

In response to your request that the report shall begin with the following statements:

1. The amount, kinds, and classes of property belonging to the Observatory.

2. The amount of such property acquired during the twelve months covered by the report.

3. The extent and kind of improvements made in the building and grounds during the past year, and the estimated cost.

4. The extent and character of the losses of property, and the origin and causes.

I have the honor to report:

	Estimated cost to replace.
(*a*) Amount and kinds of property in possession of the Observatory July 1, 1898:	
Buildings.—These include the main observatory building and a smaller photographic room, with their inclosures and appurtenances, such as connecting platform, battery shed, siderostat house, etc	$4,000
Appliances of buildings.—Consisting of steam-heating plant, refrigerating plant, temperature-control system, and storage battery for general purposes	3,500
Apparatus for research.—Including siderostat, telescopes, spectroscopes, mirrors, lenses, galvanometers, bolometers, chronographs, clocks, microscope, comparator, and many other pieces	21,000
Tools and stock in shop.—Including lathes, planer, rolls, motor, and small tools and stock	1,700
Books, drawings, and records.—Including sets of periodicals, maps, drawings of apparatus, books of reference and record, photographic plates	5,000
Total	35,200
(*b*) Within the period covered by the report there has been acquired of the various kinds of property above enumerated to the amount of	4,000
(*c*) Improvements to the building were made, including repainting and repairs to the extent of	300
(*d*) Losses suffered were trivial, and consisted in the breakage of apparatus by accident to the extent of	30

The most important features of the work of the Astrophysical Observatory during the past year have been as follows:

1. The instrumental equipment has received valuable accessions, including a highly sensitive galvanometer, designed and constructed at the Observatory; two cylindric mirrors by Brashear (which, as used for collimation of the spectroscope, are equivalent to a lens of 64 meters focal length), and, finally and most important of all, a system of cooling by the expansion of ammonia, which has made possible an extension of constant temperature conditions to cover the five months of March, April,

May, September, and October, otherwise frequently too warm. At present the change of temperature of the inner room between these warmer and the coldest winter months is only a fraction of a degree centigrade, and during an hour's observation it is generally less than one-tenth degree, the control being automatic.

2. Many bolographs of the infra-red solar spectrum have been taken, which, in consequence of these improvements, have yielded results threefold richer in "real" detail corresponding to solar and telluric absorption lines than any hitherto obtained.

3. About 40 of these bolographs have been compared, as described in the Appendix to the Secretary's Report for 1896, and 21 of the most perfect have been measured upon the comparator to determine the positions of the deflections found to be "real," or, in other words, corresponding to either solar or telluric absorption lines. These comparator measurements included about 44,000 separate observations.

There have thus been found over 700 absorption lines in the infra-red solar spectrum between wave lengths 0.76 μ and 6.0 μ, an increase of about 500 over last years' results.

4. With the purpose of making a more accurate determination of the wave lengths corresponding to the well-determined positions of the absorption lines discovered in the rock-salt prismatic spectrum, a very exact comparison of the dispersion of rock salt and fluorite has been made. This comparison will allow the indirect employment of certain recent and apparently very accurate determinations of the wave lengths in the fluorite prismatic spectrum. Apparatus has been made ready and certain preliminary observations have been taken to directly measure the dispersion of rock salt. It is hoped that these steps will result in furnishing the wave lengths of the infra-red absorption lines to a degree of accuracy corresponding to the exactness of the determination of their prismatic deviations.

5. Many interesting instances of local variations in the absorption have been noticed. Among these by far the most striking is a great decrease in the absorption at the longer wave-length side of the great band ψ at about 1.4 μ. This change occurred about February 15, 1898, and caused the bolographs to take on quite a different form at the place in question. This new form continued through the months of March and April, but in the month of May the usual form was gradually restored. It is found, by reference to former bolographs, that this marked decrease in absorption at this point takes place annually at about the same period, which coincides (fortuitously or otherwise) very nearly with that at which there is the greatest activity of growth in the vegetable kingdom. This raises the question whether the growth of vegetation does not abstract from the air great quantities of some selectively absorbing vapor active in absorption at this wave length.

Whether such be the case or not future investigation must determine, but enough variations in the absorption have been observed to indicate that the Observatory is now in condition to make advances along the line indicated in the Secretary's report for 1892, in which is pointed out the important relations of astrophysics to meteorology.

FULLER DETAILS OF THE WORK OF THE YEAR.

The best design for a sensitive galvanometer of the Thomson reflecting type was investigated, with the following results: The most suitable electrical resistance of a galvanometer for the bolographic work proposed was determined. Expressions were deduced from which the size and relative efficiency of coils of the best form and of a given resistance, but differently wound, could be computed. Computations were made which determined the best sizes of wire and the best apportionment of resistance for a coil of the most suitable total resistance wound in three sections. Four such coils were wound. Several experiments were made to determine the best construction of galvanometer needle, and two needles were made which are found to be very satisfactory. The coils were mounted in a galvanometer case constructed at the Observatory shop, and the needle was suspended by a quartz fiber of exceeding fineness.

As completed, the constants of this galvanometer are as follows:

Resistance of coils, each .... ohms..	30
Diameter of coils:	
Exterior .... millimeters..	34
Interior .... do....	2
Distance apart of coils .... do....	1.5
Weight of needle:	
First .... milligrams..	2.5
Second .... do....	6.5
Length of quartz fiber .... centimeters..	30
Diameter of quartz fiber .... millimeter..	.0015
Current in amperes giving 1^{mm} deflection on scale at 1^{m} at time of single swing of needle 10 seconds when coils are connected in series parallel (total resistance hence 30 ohms):	
With first needle	.000000000005
With second needle	.000000000020
Constant under similar conditions for galvanometer used last year.	.000000000100

Notwithstanding the greater sensitiveness of the first needle, the second has been employed in taking bolographs for two reasons: First, because its mirror (of 2 milligrams weight, by Brashear) gave better definition; and second, because the needle was steadier on account of its greater weight. It is probable that means could be devised, though not without considerable time and expense, to use the first needle with as much satisfaction as the second, and thus to gain four times in sensitiveness.

The achievement of this very considerable advance in sensitiveness made the use of both a narrower bolometer and a narrower slit to the spectrobolometer possible. The former was already at hand. To reduce the linear width of the slit would have resulted in a waste of radiations because of diffraction, a danger to which some reference was made in last year's report. To reduce the angular width of the slit by a collimating system of spherical mirrors of longer equivalent focus would have resulted in a waste of radiations, because of the vertical spreading out of the beam. In these circumstances an arrangement of cylindrical collimating mirrors was designed, with the aim to avoid both horns of this dilemma. These mirrors, one convex of 57 centimeters focus and one concave of 544 centimeters focus, were executed by Brashear and give equally as good definition as the spherical concave mirrors before employed, while reducing the angular width corresponding to a given linear aperture of the slit to about one-seventh of its former magnitude. The angular widths of slit and bolometer strip have now each been reduced to about 1.3 seconds of arc.

In the use of the new arrangements much trouble was at first experienced from "drift" and accidental disturbances of the galvanometer. The "drift" was reduced to nearly its former harmless magnitude by added precautions to avoid temperature changes. But the accidental disturbances, especially with the very narrow bolometer (0.03 millimeter), were very serious, and on days when there was the slightest breeze absolutely prohibitive to observation. It was found at length that by making the chamber occupied by the bolometer air-tight to a difference of pressure of one-third of an atmosphere all prejudicial effects of the wind, except such slight ones as were due to mechanical jarring, were avoided. Bolographs may now be taken with good results on the very windiest days.

Mechanical jarring of the galvanometer has been reduced by floating it in a pan of mercury, which is itself supported upon the table of the Julius suspension introduced here in 1895.

Bearing in mind the advantage derived from inclosing the bolometer in an air-tight compartment, an air-tight galvanometer case was designed, and having been constructed was made use of for some of the latest bolographs. The advantage derived from its use, however, proved slight.

Some decrease in the accidental deflections of the "battery record" was effected by the substitution of a "Cupron" battery of 10 cells for the great storage battery of 60 cells.

A new design for a bolometer has been prepared, in which the sensitive threads, balancing coils, and adjusting slide wire are all contained in one compact water-jacketed case with air-tight chamber. This instrument is under construction, and will, it is believed, do away with certain sources of accidental disturbance, and will be far more easy to use satisfactorily than the present form.

With the improvements above described all or in part installed, there were taken 135 bolographs between December 1, 1897, and July 1, 1898. Of these 68 were with the great rock-salt prism, 41 with the great glass prism, and 26 with a small prism of fluorite. Fifteen of those taken with the rock-salt and 8 taken with the glass prism were measured upon the comparator to establish the discovery and positions of the 700 absorption lines in the infra-red already mentioned. Fifteen taken with the fluorite prism were measured upon the comparator to determine the position of about 50 absorption lines identifiable on both the rock-salt-prism and the fluorite-prism bolographs, with the design of thus deducing the dispersion of rock-salt indirectly from the wave-length determinations of Paschen in the fluorite spectrum.

Apparatus, including a concave grating, has been arranged for the purpose of directly measuring the dispersion of rock salt, but the actual observations were not begun at the close of the period covered by this report. It is hoped that this research will make it possible to give the wave lengths of the absorption lines discovered to the degree of accuracy corresponding with that of the prismatic deviations. The Observatory is peculiarly fitted to obtain results of great accuracy, in that, first, it is in possession of such an extraordinary equipment of rock-salt prisms that one great one is provided with a thermometer at its center and used solely to determine the temperature of the optical one; second, a constant temperature may be maintained, and hence the temperature of the salt can be certainly known; third, the great sensitiveness of the bolometric apparatus allows of the employment of narrow slit widths; fourth, the bolographic method can be employed, which, being independent of circle readings, and involving instead a clock work of extreme accuracy, gives differences of deviation with extraordinary precision, reaching, as we said in last year's report, to within a second of arc.

Several energy curves, extending from the violet through the visible and infra-red spectrum as far as 5 μ, were taken with a sheet of bright copper in place of the silvered glass mirror at the siderostat. It was found that there was no appreciable difference in quality or amount of reflecting power between the copper and silver surfaces, except in the violet. Here the copper gradually deteriorated as a reflector, which accounts for its red color.

Observations have been made with the "hot box," a device similar to the gardener's hot bed intended to obtain a very high temperature from the sun's rays without the use of lenses or mirrors. A temperature of 120° C. was obtained, which is, to be sure, considerably above boiling water, but not in excess of that obtained by Herschel with the same device in South Africa many years ago. The results of the observations are merely tentative.

A considerable number of observations have been made to determine the accuracy of the bolometer as a heat-measuring device; that is, its capacity for repeating the same measure of radiations under like conditions. For this purpose successive first throws of the galvanometer were observed when the radiations from a student lamp burning good kerosene oil were alternately allowed to fall on the bolometer and cut off by a water screen at constant temperature. The variations in the deflection were very slight, and indicated rather a variation of the burning of the lamp than any inaccuracy of the bolometer. Thus for ten successive measures the average probable error of the separate observations was only 0.035 of 1 per cent, or 1 part in 3,000; but, as has just been intimated, this is a maximum value, since no absolutely constant source of heat has been found, and all the variations of the source employed are included in this 0.035 of 1 per cent. In the earlier use of the bolometer such precision would have been unattainable, owing to the nonstability of the zero point of the galvanometer, but the "drift" and tremor have now been so far eliminated as to make such results quite possible.

ACCESSIONS OF APPARATUS.

There have been added to the equipment of the Observatory during the year the following considerable pieces of apparatus:

One Richard barograph.

One Crova actinometer.

One Fuess spectrometer, with 17 centimeter circle reading to 10 seconds. Accessories consisting of reading and collimating telescopes, micrometer slit, and one liquid prism.

One reflecting galvanometer of the Thomson type, already referred to. Case constructed at Astrophysical Observatory shop; coils and needle at Astrophysical Observatory.

Two cooling tanks and ammonia compression apparatus, by De La Vergne Refrigerating Company.

Automatic temperature control for the above, by Johnson Temperature Regulating Company.

One "hot box" provided with equatorial mounting.

Two cylindric collimating mirrors by Brashear, already referred to.

Ten cells "Cupron" battery, Type I, from Umbreit & Matthes, of Leipzig, for use on the bolometer circuit.

A device for floating galvanometer upon mercury, constructed at the Astrophysical Observatory shop.

One ball-and-socket mounting for salt cylindric lens to close the bolometer case air-tight, while allowing of the adjustment of the lens for best definition. Constructed at the Astrophysical Observatory shop.

Two salt cylindric lenses for the above mounting, by Kahler.

One adjustable mounting for slit of spectroscope. Constructed at the Astrophysical Observatory shop.

One air tight galvanometer case. Designed at the Astrophysical Observatory. Constructed by Gaertner & Co.

One bolometer case, by Gaertner & Co.

Besides these pieces of apparatus actually received, there were ordered the following:

Fourteen cells of "Cupron" battery, Types I and III, with extra parts.

One Rubens thermopile.

One combined bolometer and rheostat after new design already referred to.

PERSONNEL.

The services of Mr. C. E. Mendenhall, as assistant, were secured for the period of three months beginning June 1, 1898.

SUMMARY.

In conclusion I may say that the investigations of the absorption bands in the infra-red solar spectrum, reopened by the securing of more highly sensitive bolographic apparatus during the unavoidable delay in publication of the results attained last year, has been attended this year with a degree of success exceeding anything which could be hoped for. The result now reached, which will undoubtedly be ready for the press early in the coming calendar year, includes the discovery and determination of position of over 700 such absorption lines, and is one with which the research, so far as it concerns only the discovery of new absorption lines, may suitably close.

The results we have already indicate the complete fulfillment of your expectation that this great region is the chief seat of the telluric absorption, and confirm your hopes that these researches may soon lead to knowledge of a character of permanent utility to mankind. The gradual collection and improvement of apparatus attending the prosecution of this investigation has placed the Observatory in a condition to enter under highly favorable circumstances upon other researches connected with radiant heat.

Respectfully submitted.

C. G. Abbot,
Aid, acting in Charge, Astrophysical Observatory.

Mr. S. P. Langley,
Secretary of the Smithsonian Institution.

APPENDIX VI.

REPORT OF THE LIBRARIAN FOR THE YEAR ENDING JUNE 30, 1898.

SIR: I have the honor to present herewith the report upon the operations of the library of the Smithsonian Institution during the fiscal year ended June 30, 1898.

The work of the library consists of various activities. Greatest in bulk is the reception, cataloguing, acknowledgment, and the conducting of necessary correspondence for that portion of the collection of books which is known as the Smithsonian deposit of the Library of Congress.

Next in quantity is the work connected with the books belonging to the National Museum. Small collections of reference books are being made for the Zoological Park, the Astrophysical Observatory, and the Exchange Service. A special section of law reference for the use of the Institution is also being established, and a section relating to ærodromics is maintained. A small library has been purchased for the use of the employees of the Institution. The Museum library has itself 21 sections. In addition to the care of these branches of the library work, the library has been frequently referred to for information, bibliographical and otherwise.

SMITHSONIAN DEPOSIT.

The entry numbers of accessions to the Smithsonian deposit in the Library of Congress extend from 364973 to 390914.

The following table gives an analysis in volumes, parts of volumes, pamphlets, and charts, of the accessions during the year:

Publications received between July 1, 1897, and June 30, 1898.

	Quarto or larger.	Octavo or smaller.	Total.
Volumes	962	1,407	2,369
Parts of volumes	21,204	8,925	30,129
Pamphlets	746	4,272	5,018
Charts			418
Total			37,934

This exhibits an increase over 1897 of more than 4,500 entries for this branch alone. One-fourth of this matter has been temporarily retained in the library of the United States National Museum for use.

In addition to this there have been added to the Secretary's library, office library, employees library, and library of the Astrophysical Observatory, 701 volumes and pamphlets and 2,080 parts of volumes, making a total of 2,781, and a grand total of 40,715 volumes, parts of volumes, pamphlets, and charts of accessions for the year.

The Library of Congress was removed from the old quarters in the Capitol to the new Library building, in the months of August and September and was reopened for use in November, 1897. The east stack, the smaller of the three stacks in the Library, was set apart for the Smithsonian deposit, and a commodious room directly adjoining this stack on the main floor was assigned as an office and work room. Into this a large part of the accumulation of the last ten years was placed, and these have been to a certain extent arranged and catalogued. It is the desire and intent of the

Librarian of Congress that all the Smithsonian books shall be placed together in this stack and steps are being taken toward that end. The bill passed by Congress providing for the arrangement and organization of the Library in its new building, however, made no provision, either for this work or for the care of the Smithsonian stack, and it has resulted that all work in connection with this collection of books must be done in the spare time of persons who already had other duties. While, therefore, a great deal has been accomplished in a comparatively short space of time, the Smithsonian deposit is as yet by no means in a satisfactory condition.

SECRETARY'S LIBRARY.

The Secretary's library, a special collection of reference books for the use of the Secretary, which may be, under certain restrictions, consulted by other persons, now numbers about 600 volumes. These books are kept in the Secretary's office and in rooms in close proximity to it. A new bookcase was assigned, thus rendering possible a better disposition of the books than heretofore. The increase of this collection was 42 volumes and 182 parts of periodicals.

ASTROPHYSICAL OBSERVATORY.

With the establishment of the Observatory in 1891 it was found necessary to provide a small collection of books for its use. In view of the crowded condition of the Observatory and of the fact that its building was not fireproof, the Secretary desired that as few books as possible be kept in the Observatory. A room was accordingly assigned for this purpose on the third floor of the Smithsonian building, only a few books and pamphlets being kept in the Observatory itself. The increase of this library during the past year has been 30 volumes and 357 parts of periodicals.

LIBRARY OF THE ZOOLOGICAL PARK.

A small collection of books relating principally to parks and zoological gardens and other matters intimately associated with the work of the Park, are kept in a room in the Holt House. In accordance with the Secretary's instructions, and with the advice of the Superintendent of the Park, I shall endeavor in the course of next year to enlarge this collection, more especially in books relating to parks, park architecture, etc. It is only with great difficulty that sets of guides to zoological gardens are obtained, as these publications are fleeting in their nature and not usually preserved. The Secretary, in connection with the repairs in the Holt House, the office of the Zoological Park, has sanctioned improved facilities for the maintenance of this collection of books.

EMPLOYEES' LIBRARY.

There has been purchased a collection of about 400 books of literature, good fiction, history, biography, and popular science, which together with the bound volumes of popular periodicals and the current numbers form a circulating library for the employees of the institution. The library is open to all employees of the institution under the following regulations:

1. All persons desiring to withdraw books must first file with the librarian a certificate of identity from the chief clerk of the Bureau or office in which they are employed.

2. The library will be open for the withdrawal and return of books from 12 m. to 1 p. m., and from 4 to 4.30 p. m.

3. Books may be taken for the period of one week, with the privilege of one renewal.

4. The popular magazines on the table may be taken out at 4 o'clock p. m., to be returned at 9 a. m. the following morning.

5. Any book or periodical injured, defaced, or lost, while in the possession of the borrower, must be replaced by a new copy.

6. Before a book is borrowed it must first be submitted to the librarian for registry.

7. No person will be permitted to take more than one book and magazine at a time.

8. The librarian is authorized to suspend or refuse the issue of books to persons violating any of the above rules.

The members of the staff and the employees of the institution have already begun to use this library, and I feel sure that it will be a source of instruction and pleasure to many.

EXCHANGE SERVICE.

For the Exchanges the attempt has been made to secure as good a collection of directories and books containing addresses as possible. The greater part of such publications are received in exchange, but some few have been purchased.

LAW REFERENCE LIBRARY.

The work of the Institution and its bureaus requires the reference to so many public documents and law books, that the necessity has been found for the establishment of a small collection of works on this subject. These are provided by the Institution and are for the present deposited in the office of the chief clerk of the National Museum.

LIBRARY OF THE UNITED STATES NATIONAL MUSEUM.

The Museum library has received during the year 441 books, 797 pamphlets, and 4,926 parts of periodicals. Four hundred and seven volumes, 1,148 pamphlets, and 11,817 parts of periodicals belonging to the Smithsonian deposit have been temporarily retained for the National Museum. The late Dr. G. Brown Goode had formed a collection of scientific works relating more especially to museum work and natural history, which, during his lifetime, had always been at the disposal of his associates in the Museum. The work of the Museum would have been seriously hampered had this collection gone elsewhere. By an arrangement with his executor, an offer of the collection was made to the Institution, and its value having been appraised by Dr. Theodore Gill and myself, the Secretary applied to Congress for a special appropriation for the purchase of this collection. This has been duly authorized by Congress, and in the coming year this valuable library, consisting of 2,900 volumes, 18,000 pamphlets, and 1,800 autographs and engravings, will become the property of the National Museum.

Over 3,000 volumes were placed in the sectional libraries during the past year, 3,500 books were borrowed and returned, and 17,127 books were consulted in the library itself. This indicates a greater use of the library than at any time heretofore. A more detailed account of the operations of the Museum library, together with a list of accessions by gift, will be found in the report of the National Museum.

PURCHASE OF BOOKS.

In the legislative, executive, and judicial act approved by the President on March 15, 1898, the following proviso was contained:

That hereafter law books, books of reference, and periodicals for use of any executive department, or other Government establishment not under an executive department, at the seat of Government, shall not be purchased or paid for from any appropriation made for contingent expenses or for any specific or general purpose unless such purpose is authorized and payment therefor specifically provided in the law granting the appropriation.

As this portion of the act became effective immediately upon its passage no books could be purchased during the remainder of the fiscal year. It has therefore been found necessary in the estimates under the Smithsonian Institution for the coming year to provide in some way for the purchase of books absolutely indispensable for the bureaus of the Institution. An appropriation of $2,000 for the purchase of books for the National Museum was authorized by Congress, and for other bureaus special clauses permitting "the purchase of necessary books and periodicals" were introduced in the sundry civil act passed July 1, 1898.

The correspondence carried on was largely in accordance with the general instruction for the increase of the library or for completing imperfect series. One thousand and eighteen letters were written, with the result that 427 new exchanges have been added to the list and 329 defective series either completed or filled out as far as the publishers were able to make good missing parts. The lists collected under the Secretary's direction have been exhausted, but so many new periodicals and societies have sprung up that the year has been fully occupied in undertaking to secure these new publications. I beg to recommend that this work be continued in the future on two lines—first, by a methodical attempt to secure the publications of the new learned societies which have been established all over the world, and secondly, to secure, where possible, the newer scientific and technical periodicals. The care of correspondence and the revision of lists in connection with this work has grown in magnitude, and more could be done if more aid could be had. Only trained assistants with a knowledge of foreign languages could do this work, as the correspondence received is in all modern languages, even including modern Greek.

The Secretary of State nominated the Secretary of the Institution and myself delegates to the second conference on an international catalogue of scientific literature, to be held in London during the coming autumn.

Respectfully submitted.

CYRUS ADLER, *Librarian.*

Mr. S. P. LANGLEY,
Secretary of the Smithsonian Institution.

Appendix VII.

REPORT OF THE EDITOR FOR THE YEAR ENDING JUNE 30, 1898.

Sir: I have the honor to submit the following report on the publications of the Smithsonian Institution for the year ending June 30, 1898:

The publications of the Institution itself are in three series, the Contributions to Knowledge in quarto form, and the Miscellaneous Collections and Smithsonian Report in octavo. Under the direction of the Institution are also published the Proceedings and Bulletins of the National Museum, the Annual Report of the Bureau of Ethnology, and the Annual Report of the American Historical Association.

The libraries and institutions to which the "Contributions" and "Collections" could be sent has always been very limited in number, though scattered widely throughout the world, and in extending the number of libraries it has not been possible to furnish complete sets, but merely future volumes. Fifteen hundred copies of these series are now printed, but this number, though all that the limited income of the Institution can furnish, has not been found sufficient to meet the demand.

The general distribution is made, first, to those learned societies of the first class which give to the Institution in return complete sets of their own publications; secondly, to colleges of the first class furnishing catalogues of their libraries and students and publications relative to their organization and history; thirdly, to public libraries in this country having 25,000 volumes; fourthly, they are presented in some cases to still smaller libraries, especially if no other copies of the Smithsonian publications are given in the same place, and a large district would be otherwise unsupplied; lastly, to institutions devoted exclusively to the promotion of particular branches of knowledge such of its publications are given as relate to their special objects. These rules apply chiefly to distribution in the United States. The number sent to foreign countries, under somewhat different conditions, is about the same as that distributed in this country.

The edition of the annual report at the disposal of the Institution is 7,000 copies, which is sufficiently large to permit of a comparatively wide distribution, though the number printed is less than in former years.

Requests from individuals are complied with when possible, but, as a rule, it is found necessary to restrict the distribution of all publications to libraries and institutions of learning.

In the original "programme of organization" approved by the Regents in 1847 there was specified among the details of the plan for diffusing knowledge "the publication of a series of reports giving an account of new discoveries in science, and of the changes made from year to year in all branches of knowledge not strictly professional." And it was added that "The reports are to be prepared by collaborators eminent in the different branches of knowledge."

In the report for 1854 appeared for the first time an "appendix," containing an account of American explorations for the years 1853 and 1854, by Prof. S. F. Baird; a full report of lectures delivered before the Institution by Marsh, Brainard, Loomis, Channing, Reed, and Russell; extracts from the scientific correspondence of the Institution, and miscellaneous papers relating to American archæology, geology, etc.

The general appendix to the annual report has been regularly continued to the present time, and has served to bring the Smithsonian report into great popular demand. It has long been the custom to enrich the report with memoirs illustrating the more remarkable and important developments in physical and biological discovery, as well as showing the general character of the operations of the Institution; and this purpose has, during the greater part of its history, been carried out largely by the publication of such papers as would possess an interest to all attracted by scientific progress.

In 1880 Secretary Baird, induced in part by the discontinuance of an annual summary of progress which for thirty years previous had been issued by well-known private publishing firms, had prepared by competent collaborators a series of abstracts, showing concisely the prominent features of recent scientific progress in astronomy, geology, meteorology, physics, chemistry, mineralogy, botany, zoology, and anthropology. This latter plan was continued, though not altogether satisfactorily, down to and including the year 1888.

In the report for 1889 a return was made to the earlier method of presenting a miscellaneous selection of papers (some of them original) embracing a considerable range of scientific investigation and discussion.

So much trouble has been experienced in securing papers of the character desired for the general appendix of the report that the Secretary has stated his ideas definitely in the following printed rules for the guidance of those who cooperate in selecting the articles:

RULES FOR THE SELECTION OF PAPERS FOR THE GENERAL APPENDIX TO THE ANNUAL REPORT.

So much difficulty has been found in obtaining the class of papers desired by the Secretary for the appendix to his annual report that he takes this method of expressing his wishes to those gentlemen who are good enough to favor him with their cooperation in making a selection.

He asks that it may be remembered:

1. That these papers have a purpose distinct from any others published by the Institution. They are only occasionally original contributions to science. They are not for the professional reader only, or even chiefly, but they are addressed to that large body of the public which has a general interest in scientific matters without special knowledge.
2. That while it is always a recommendation that they should have been written by recognized authorities, yet this is of minor importance if the articles are sound expositions of the subject. The essential thing is that they should be not only sound and instructive, but timely and interesting to the nonprofessional reader, and in that good sense popular. If they are accompanied by illustrations all the better.
3. As they are wanted to serve as a kind of survey of the whole field of the sciences, both physical and biological, for the past year, it is as a rule impracticable to print more than one on any particular subject. While the Secretary will be very glad, then, to have any number suggested in English, French or German which will meet these requirements, he will not expect as a rule to make use of more than one.
4. The papers may be, in exceptional cases, as brief as 1,000 words. They should rarely exceed 10,000 or 12,000.
5. At the risk of needless iteration it is repeated that what is wanted is not for the specialist, but interesting and popular expositions of what the specialist knows to be sound and opportune.

S. P. LANGLEY, *Secretary.*

WASHINGTON, D. C., *March, 1898.*

I. CONTRIBUTIONS TO KNOWLEDGE.

One new memoir of the "Contributions," on Specific Heat Ratios, has been published, and Secretary Langley's memoir on Internal Work of the Wind has been reprinted in a small edition with some slight additions and changes.

No. 1126. A Determination of the Ratio (Kappa) of the Specific Heats at Constant Pressure and at Constant Volume for Air, Oxygen, Carbon-Dioxide, and Hydrogen. By O. Lummer and E. Pringsheim. City of Washington. Published by the Smithsonian Institution, 1898. 4°. V + 29 pp., with 1 plate and 3 text figures. (From Smithsonian Contributions to Knowledge, Vol. XXIX.)

This memoir is the result of a series of investigations by Drs. Lummer and Pringshime, aided by a grant from the Hodgkins fund.

II. MISCELLANEOUS COLLECTIONS.

Of the Miscellaneous Collections five new works have been published since the editor's last report, and the Smithsonian Meteorological, Geographical, and Physical Tables have been reprinted.

At the close of the year much progress had been made in printing a Supplement to Bolton's Bibliography of Chemistry, which will include about 4,000 additional titles of chemical publications.

Volumes XXXVII, XXXVIII and XL of the Collections were also completed and the covers, titles, and other preliminary pages distributed. Parts of Volume XXXIX have been issued and the whole volume will soon be completed.

The new works are as follows: Catalogue of Scientific and Technical Periodicals; Catalogue of Pacific Coast Earthquakes; Review and Bibliography of Metallic Carbides; Bibliography of Metals of the Platinum Group; and a report on the effects of impure air on the vital resistance of animals to disease.

No. 1076. A Catalogue of Scientific and Technical Periodicals, 1665–1895. By Henry Carrington Bolton. Second edition. City of Washington. Published by the Smithsonian Institution, 1897. 8°. VII + 1247 pp. (From Smithsonian Miscellaneous Collections, Vol. XL.)

In the preface the author says:

"As was stated in the first edition of this catalogue, issued in 1885, it is intended to contain the principal independent periodicals of every branch of pure and applied science published in all countries from the rise of this literature to the present time. The compiler has endeavored to give full titles, names of editors, sequence of series, and other bibliographical details, and to arrange the whole on a simple plan convenient for reference. The range of topics is shown in the Index of Subjects; while medicine has been excluded, anatomy, physiology, and veterinary science, being related to zoology, have been admitted. With a few exceptions serials constituting transactions of learned societies have been omitted; those admitted either form part of a series begun or ending in an independent periodical, or are presumably not exclusively devoted to the proceedings of the societies by which they are edited.

"Some of the journals included in this catalogue are of doubtful scientific value, and the right of some to be classed as periodicals is questionable. In these and other debatable cases many titles have been admitted on the ground that 'in a bibliography it is much better that a book should be found which is not sought, than that one should be sought for and not found.' (Zuchold.)

"The plan of the catalogue is as follows: The titles are arranged alphabetically by the first word, the articles and the adjective 'new' (with its equivalents in different languages) alone excepted. The various titles borne by a periodical at different times are arranged in chronological order under the first or earliest titles of the series. Cross-references have been freely introduced, and are of four kinds: (1) from the later to the first title of a periodical which has suffered changes in title; (2) from short titles in common use to the correct designations; (3) from the names of the principal editors to the journals conducted by them; (4) in the case of astronomical publications, from the places in which the observatories are situated to the titles of the periodicals issued therefrom.

"Part I of the alphabetical catalogue is a reprint from the plates of the first edition after having made the changes necessary to bring the titles down to date. Part II contains additions to the titles of Part I that could not be inserted in the plates, together with about 3,600 new titles. The letter 's' following a title in Part I refers to additional information in Part II. Numbers inclosed in brackets in Part II denote that earlier data will be found in Part I.

"The chronological tables are designed to give the date of the publication of each volume of the periodicals entered, as explained on pages 1018 and 1019. By these tables the date of a given volume in a given series of a given work may be found, or the number of a volume may be ascertained when the date only is known. Librarians will find the tables of service in determining bibliographical data of series not in their collections. The alphabetical list of periodicals should always be consulted in connection with the chronological tables. An index to the periodicals contained in the tables will be found at their close.

"The library check list, showing in what American libraries the periodicals may be found, is an attempt to carry out on a continental scale that which has been done by librarians in several localities. The data were gathered by means of circulars and forms distributed by the Smithsonian Institution to about 200 libraries. The returns from 133 libraries were codified by the institution. It is believed that the new check list to the second edition is far more complete and accurate than the former, and justifies the delay of nearly twelve months in the publication of the volume. The number of periodicals noted is about 3,160 out of the 8,600 in the catalogue.

"The material for this work has been gathered from all available bibliographies and by personal examination of the shelves and of the printed and manuscript catalogues of many libraries in the United States, England, France, Belgium, Germany, and Italy. As a last resort circulars were sent out through the Smithsonian Institution to publishers in several countries asking for specimen numbers of their journals; the titles were then transcribed from the numbers received."

No. 1084. Bibliography of the Metals of the Platinum Group: Platinum, Palladium, Iridium, Rhodium, Osmium, Ruthenium. 1748–1896. By Jas. Lewis Howe. City of Washington. Published by the Smithsonian Institution, 1897. 8°. 318 pp. (Forms part of Vol. XXXVIII, Smithsonian Miscellaneous Collections.)

No. 1087. A Catalogue of Earthquakes on the Pacific Coast, 1769-1897. By Edward S. Holden, LL. D. City of Washington. Published by the Smithsonian Institution. 1898. 8°. IV + 253 pp., with 5 plates and 6 text figures. (Forms part of Vol. XXXVII, Smithsonian Miscellaneous Collections.)

This paper is an exhaustive list of earthquakes recorded on the Pacific coast from 1769 to 1897 and includes a complete account of the earthquake observations at Mount Hamilton during the years 1887 to 1897, together with an abstract of information which has been collected regarding Pacific coast earthquakes during that period.

No. 1090. Review and Bibliography of the Metallic Carbides. By J. A. Mathews, M. S., M. A., F. C. S. City of Washington. Published by the Smithsonian Institution. 1898. 32 pp. (Forms part of Vol. XXXVIII, Smithsonian Miscellaneous Collections.)

In general plan the work gives a condensed account of the methods of preparation, and the physical and chemical properties of the carbides, arranged in alphabetical order, following each descriptive portion with references to the literature bearing thereon. The author says:

"Within the last five years the renewed attention of chemists has been turned toward this class of compounds, and new carbides have been produced in rapid succession. Experiments upon the reduction of metallic oxides by means of carbon in an electric furnace have resulted in the production of many of the newly discovered carbides. In studying the literature of these compounds the work of one man is especially noticeable. More than to all other chemists together is praise due M. Henri Moissan for the untiring energy with which he has investigated the carbo-metallic compounds. So often has he astonished chemists with the results of his electro-chemical experiments that new discoveries by him are likely to be considered as a matter of course. M. Moissan's work upon artificial diamonds is one of the greatest achievements of science in imitating nature's methods.

"In conducting his experiments Moissan makes use of an electric furnace of very simple construction. It consists of a limestone block, in the upper surface of which is chiseled a rectangular cavity, which is lined with a coating of magnesia and of carbon. Through opposite sides of the block are inserted stout carbon electrodes, and through one of the other sides is an opening through which a carbon tube is inserted. In this tube the materials to be heated are placed and thus inserted into the arc. It is estimated that a temperature of 4,000° is obtained in this furnace. Before using the furnace it is covered with another piece of limestone, on the lower side of which are layers of magnesia and carbon, which fit into or cover the cavity of the lower block. So poorly do these materials conduct heat that the hand may be kept on the outside of the furnace for several minutes after the current is started."

No. 1125. An investigation on the Influence upon the Vital Resistance of Animals to the Micro-organisms of Disease brought about by Prolonged Sojourn in Impure Atmosphere. By D. H. Bergey, M. D. City of Washington. Published by the Smithsonian Institution, 1898. 8°. 10 pp. (Forms part of Smithsonian Miscellaneous Collections, Vol. XXXIX.)

This is a report of an investigation outlined by and conducted under the supervision of Drs. John S. Billings and S. Weir Mitchell, in which an attempt has been made to determine whether impure atmosphere produces detrimental influence upon the animal organism, as shown in greater susceptibility to certain diseases. The impurities tested were carbonic-acid gas and respiratory impurities, and the micro-organisms were staphylococcus, diphtheria, and bacillus tuberculosis. Dr. Bergey summarizes the results of his investigation as follows:

"In the staphylococcus and diphtheria inoculations the cultures used appear to have been insufficiently attenuated to show any difference in the effect produced upon the animals under experiment and the control animals. It is, however, very doubtful whether cultures of these organisms could be attenuated to such a degree as to still kill a weakened animal and not kill a control, healthy animal.

"The anthrax vaccines used do not kill a healthy guinea pig, but it was expected that the animals might present sufficient lowering of the vitality to become affected by the vaccines. This, however, was not the case. The animals having failed to die from the effects of the anthrax vaccines, they were then inoculated with an attenuated culture of tuberculosis. All the animals under experiment died much earlier than the control animals. These results indicate a lowered vitality. Whether this lowered vitality was brought about by the atmospheric conditions under which they had lived, or whether it was brought about solely through changes in their diet while under experiment, or whether both these causes were active in producing the result, it is impossible to say. The animals lost flesh and decreased in weight while under experiment. It is not improbable that the loss in weight and the decrease in vitality are both traceable to the same causes."

No. 978. Smithsonian Miscellaneous Collections. Vol. XXXVII. Washington City. Published by the Smithsonian Institution, 1897. 8°. 918 pp.

CONTENTS.

Index to Genera and Species of Foraminifera. By Charles Davies Sherborn. Parts I and II. Washington, 1893, 1896. (Numbers 856, 1031.)

Mountain Observatories of America and Europe. By Edward S. Holden. Washington, 1896. (Number 1035.)

Virginia Cartography. By P. Lee Phillips. Washington, 1896. (Number 1039.)

Catalogue of Earthquakes on Pacific Coast, 1769 to 1897. By Edward S. Holden. Washington, 1898. (Number 1087.)

No. 979. Smithsonian Miscellaneous Collections. Vol. XXXVIII. Washington City. Published by the Smithsonian Institution, 1898. 8°. 1008 pp.

CONTENTS.

Varieties of Human Species. By Giuseppe Sergi. Washington, 1894. (Number 969.)

Bibliography of Aceto Acetic Ester. By Paul H. Seymour. Washington, 1894. (Number 970.)

Indexes to Literatures of Cerium and Lanthanum. By W. H. Magee. Washington, 1895. (Number 971.)

Index to Literature of Didymium. By A. C. Langmuir. Washington, 1894. (Number 972.)

Recalculation of Atomic Weights. New edition. By F. W. Clarke. Washington, 1897. (Number 1075.)

Bibliography of Metals of the Platinum Group. By Jas. Lewis Howe. Washington, 1897. (Number 1084.)

Review and Bibliography of the Metallic Carbides. By J. A. Mathews. Washington, 1898. (Number 1090.)

No. 1093. Smithsonian Miscellaneous Collections. Vol. XL. Washington City. Published by the Smithsonian Institution, 1898. 8°. 1259 pp.

CONTENTS.

A catalogue of Scientific and Technical Periodicals, 1665-1895. By H. C. Bolton. Second edition, 1897.

III. SMITHSONIAN ANNUAL REPORTS.

The Annual Reports of the Institution for the years 1896 and 1897 had not been distributed at the close of the fiscal year, though both volumes were nearing completion by the Public Printer. The separate papers of the 1896 volume were about ready for delivery and the whole volume was in the bindery. Presswork was in progress on the report for 1897, and it is expected that both reports will soon be published in the new style of binding recently adopted.

The general appendix of the report for 1897 will contain the following papers:

Aspects of American Astronomy, by Simon Newcomb.

The Beginnings of American Astronomy, by Edward S. Holden.

The Evolution of Satellites, by G. H. Darwin.

Electrical Advance in the Past Ten Years, by Elihu Thomson.

The X-Rays, by W. C. Röntgen.

Cathode Rays, by J. J. Thomson.

Story of Experiments in Mechanical Flight, by S. P. Langley.

On Soaring Flight, by E. C. Huffaker.

The Revival of Alchemy, by H. C. Bolton

Diamonds, by William Crookes.

The Discovery of New Elements within the Last Twenty-Five Years, by Clemens Winkler.

An Undiscovered Gas, by William Ramsay.

Fluorine, by Henri Moissan.

Light, and its Artificial Production, by O. Lummer.

Explorations of the Upper Atmosphere, by Henri de Graffigny.

The Exploration of the Free Air by Means of Kites at Blue Hill Observatory, by A. Lawrence Rotch.

The Debt of the World to Pure Science, by John J. Stevenson.

The Age of the Earth as an Abode Fitted for Life, by Lord Kelvin.

Rising of the Land Around Hudson Bay, by Robert Bell.

Crater Lake, Oregon, by J. S. Diller.

The Function and Field of Geography, by J. Scott Keltie.

Letters from the Andrée Party.

Scientific Advantages of an Antarctic Expedition, by John Murray and others.

Recent Progress in Physiology, by Michael Foster.

The Factors of Organic Evolution from a Botanical Standpoint, by L. H. Bailey.

The Law which Underlies Protective Coloration, by Abbott H. Thayer.

Life History Studies of Animals, by L. C. Miall.

The Royal Menagerie of France, and the National Menagerie, Established on the 14th of Brumaire, of the Year II (November 4, 1793), by E. T. Hamy.

Botanical Opportunity, by William Trelease.

Mescal: A New Artificial Paradise, by Havelock Ellis.

The Unity of the Human Species, by Marquis de Nadaillac.

Recent Research in Egypt, by W. M. Flinders-Petrie.

A Study of the Omaha Tribe: The Import of the Totem, by Alice C. Fletcher.

A New Group of Stone Implements from the Southern Shores of Lake Michigan, by W. A. Phillips.

A Preliminary Account of Archæological Field Work in Arizona in 1897, by J. Walter Fewkes.

The Building for the Library of Congress, by Bernard R. Green.

Francis Amasa Walker, by George F. Hoar and Carroll D. Wright.

The Museum volume of the Smithsonian Report for 1895 was distributed and the volumes for 1896 and 1897 were well advanced toward publication at the close of the fiscal year. The 1896 volume was nearly all in type, and also a portion of the Report for 1897.

No. 1078. B. Annual Report of the Board of Regents of the Smithsonian Institution, showing the operations, expenditures, and condition of the Institution for the year ending June 30, 1895. Report of the United States National Museum. Washington: Government Printing Office, 1897. 8°. xx, 1080 pp., 154 plates and 382 text figures.

Part I of this volume contains a report upon the condition and progress of the United States National Museum during the year ending June 30, 1895, by Assistant Secretary G. Brown Goode, with appendices, and Part II consists of papers describing and illustrating the collections in the National Museum, as follows: The Social

Organizations and the Secret Societies of the Kwakiutl Indians, by Franz Boas, pp. 311–738; The Graphic Art of the Eskimo, by Walter James Hoffman, pp. 739–968; Notes on the Geology and Natural History of the Peninsula of Lower California, by George P. Merrill, pp. 969–994; The Mineralogical Collections in the United States National Museum, by Wirt Tassin, pp. 995–1000; The Tongues of Birds, by Frederic A. Lucas, pp. 1001–1020; The Ontonagon Copper Bowlder in the United States National Museum, by Charles Moore, pp. 1021–1030; Taxidermical Methods in the Leyden Museum, Holland, by R. W. Shufeldt, pp. 1031–1037; The Antiquity of the Red Race in America, by Thomas Wilson, pp. 1039–1045.

IV. PAPERS FROM ANNUAL REPORT.

No. 1074. Report of S. P. Langley, Secretary of the Smithsonian Institution, for the year ending June 30, 1896. (From the Smithsonian Report for 1896.) Octavo pamphlet of 77 pages, with 6 plates.

No. 1094. Journal of Proceedings of the Board of Regents of the Smithsonian Institution. Report of executive committee. Acts and resolutions of Congress. (From the Smithsonian Report of 1896.) Octavo pamphlet of 41 pages.

No. 1095. The Problems of Astronomy, by Simon Newcomb. (From the Smithsonian Report for 1896.) Octavo pamphlet of 10 pages.

No. 1096. The Investigations of Herman von Helmholtz on the Fundamental Principles of Mathematics and Mechanics, by Leo Koenigsberger. (From the Smithsonian Report for 1896.) Octavo pamphlet of 32 pages.

No. 1097. Physical Phenomena of the Upper Regions of the Atmosphere, by Alfred Cornu. (From the Smithsonian Report for 1896.) Octavo pamphlet of 9 pages, with 1 plate.

No. 1098. New Researches on Liquid Air, by Professor Dewar. (From the Smithsonian Report for 1896.) Octavo pamphlet of 14 pages, with 6 plates.

No. 1099. Meteorological Observatories, by Richard Inwards. (From the Smithsonian Report for 1896.) Octavo pamphlet of 18 pages.

No. 1100. Color Photography by means of Body Colors, and Mechanical Adaptation in Nature, by Otto Wiener. (From the Smithsonian Report for 1896.) Octavo pamphlet of 39 pages.

No. 1101. Present Status of the Transmission and Distribution of Electrical Energy, by Louis Duncan. (From the Smithsonian Report for 1896.) Octavo pamphlet of 15 pages.

No. 1102. The Utilization of Niagara, by Thomas Commerford Martin. (From the Smithsonian Report for 1896.) Octavo pamphlet of 10 pages, with 3 plates.

No. 1103. Earth-crust Movements and their Causes, by Joseph Le Conte. (From the Smithsonian Report for 1896.) Octavo pamphlet of 12 pages.

No. 1104. The Physical Geography of Australia, by J. P. Thomson. (From the Smithsonian Report for 1896.) Octavo pamphlet of 28 pages.

No. 1105. Arctic Explorations, by A. H. Markham. (From the Smithsonian Report for 1896.) Octavo pamphlet of 24 pages.

No. 1106. The Animal as a Prime Mover, by R. H. Thurston. (From the Smithsonian Report for 1896.) Octavo pamphlet of 42 pages.

No. 1107. Recent Advances in Science, and their Bearing on Medicine and Surgery, by Michael Foster. (From the Smithsonian Report for 1896.) Octavo pamphlet of 26 pages.

No. 1108. Ludwig and Modern Physiology, by J. Burdon Sanderson. (From the Smithsonian Report for 1896.) Octavo pamphlet of 15 pages.

No. 1109. The Processes of Life Revealed by the Microscope; a Plea for Physiological Histology, by Simon Henry Gage. (From the Smithsonian Report for 1896.) Octavo pamphlet of 16 pages, with 6 plates.

No. 1110. The General Conditions of Existence and Distribution of Marine Organisms, by Dr. John Murray. (From the Smithsonian Report for 1896.) Octavo pamphlet of 13 pages.

No. 1111. The Biologic Relations of Plants and Ants, by Dr. Heim. (From the Smithsonian Report for 1896.) Octavo pamphlet of 45 pages, with 6 plates.

No. 1112. Some Questions of Nomenclature, by Theodore Gill. (From the Smithsonian Report for 1896.) Octavo pamphlet of 27 pages.

No. 1113. The War with the Microbes, by E. A. De Schweinitz. (From the Smithsonian Report for 1896.) Octavo pamphlet of 12 pages.

No. 1114. The Rarer Metals and their Alloys, by W. Chandler Roberts-Austen. (From the Smithsonian Report for 1896.) Octavo pamphlet of 19 pages, with 4 plates.

No. 1115. Preliminary Account of an Expedition to the Pueblo Ruins near Winslow, Ariz., in 1896. (From the Smithsonian Report for 1896.) Octavo pamphlet of 23 pages, with 29 plates.

No. 1116. Was Primitive Man a Modern Savage? by Talcott Williams. (From the Smithsonian Report for 1896.) Octavo pamphlet of 8 pages.

No. 1117. Bows and Arrows in Central Brazil, by Hermann Meyer. (From the Smithsonian Report for 1896.) Octavo pamphlet of 42 pages, with 5 plates.

No. 1118. Account of the Work of the Service of Antiquities of Egypt and of the Egyptian Institute during the years 1892, 1893, and 1894, by J. De Morgan. (From the Smithsonian Report for 1896.) Octavo pamphlet of 22 pages.

No. 1119. Report upon the Exhibit of the Smithsonian Institution and the United States National Museum at the Cotton States and International Exposition, Atlanta, Ga., 1895. (From the Smithsonian Report for 1896.) Octavo pamphlet of 23 pages, with 1 plate.

No. 1120. Memorial of Dr. Joseph M. Toner, by Ainsworth R. Spofford. (From the Smithsonian Report for 1896.) Octavo pamphlet of 7 pages.

No. 1121. William Bower Taylor, by William J. Rhees. (From the Smithsonian Report for 1896.) Octavo pamphlet of 12 pages.

No. 1122. Joseph Prestwich, by H. B. Woodward. (From the Smithsonian Report for 1896.) Octavo pamphlet of 10 pages.

No. 1123. Henry Brugsch, by G. Maspero. (From the Smithsonian Report for 1896.) Octavo pamphlet of 6 pages.

No. 1124. A Biographical Sketch of John Adam Ryder, by Harrison Allen. (From the Smithsonian Report for 1896.) Octavo pamphlet of 15 pages.

V. SPECIAL PUBLICATIONS.

No. 1091. Publications of the Smithsonian Institution available for distribution April, 1898. City of Washington, April, 1898. 8°. 29 pp. Contains a list of such publications of the Institution proper as are in stock available for sale or exchange.

VI. NATIONAL MUSEUM PUBLICATIONS.

The publications of the National Museum issued during the year were as follows:

Museum Report for 1895, referred to under Smithsonian Report.

Proceedings of the United States National Museum, Vol. XIX, published under the direction of the Smithsonian Institution, Washington: Government Printing Office, 1897. 8°. VIII, 864 pp., 68 plates.

This volume contains the following papers:

Descriptions of new Cynipidous Galls and Gall-Wasps in the United States National Museum, by William H. Ashmead; Fishes collected at Bering and Copper Islands by Nikolai A. Grebnitski and Leonhard Stejneger, by Tarleton H. Bean and Barton A. Bean; Notes on Fishes collected in Kamchatka and Japan by Leonhard Stejneger and Nicolai A. Grebnitski, with a description of a new Blenny, by Tarleton H. Bean and Barton A. Bean; The Food Plants of Scale Insects (Coccidæ), by T. D. A. Cockerell; Report on the Fishes dredged in Deep Water, near the Hawaiian Islands, with Descriptions and Figures of Twenty-three new Species, by Frank Cramer and Charles Henry Gilbert; Report on the Mollusks collected by the International Boundary Commission of the United States and Mexico, 1892–1894, by

William Healey Dall; Descriptions of Tertiary Fossils from the Antillean Region, by William Healey Dall and R. J. Lechmere Guppy; Descriptions of Twenty-two new Species of Fishes collected by the steamer *Albatross*, of the United States Fish Commission, by Charles Henry Gilbert; Descriptions of New Species of North American Coleoptera in the Families Cerambycidæ and Scarabæidæ, by Martin L. Linell; On the Insects collected by Dr. Abbott on the Seychelles, Aldabra, Glorioso, and Providence Islands, with Descriptions of Nine new Species of Coleoptera, by Martin L. Linell; Notes on Larval Cestode Parasites of Fishes, by Edwin Linton; Is the Florida Box Tortoise a Distinct Species? by Einar Lönnberg; Preliminary Diagnoses of new Mammals from the Mexican Border of the United States, by Edgar A. Mearns; Descriptions of Six new Mammals from North America, by Edgar A. Mearns; Description of a new Genus and Four new Species of Crabs from the West Indies, by Mary J. Rathbun; Catalogue of a collection of Birds made by Dr. W. L. Abbott in Madagascar, with descriptions of three new Species, by Charles W. Richmond; Birds of the Galapagos Archipelago, by Robert Ridgway; On the Fossil Phyllopod Genera Dipeltis and Protocaris, of the Family Apodidæ, by Charles Schuchert; On the Genus Remondia, Gabb, a group of Cretaceous Bivalve Mollusks, by Timothy W. Stanton; A Revision of the Adult Tapeworms of Hares and Rabbits, by Ch. Wardell Stiles; A Revision of the American Moles, by Frederick W. True; Summary of the Hemiptera of Japan, presented to the United States National Museum by Professor Mitzukuri, by Philip R. Uhler; Cambrian Brachiopoda: Genera Iphidea and Yorkia, with descriptions of new species of each; and of the genus Acrothele, by Charles D. Walcott.

The following papers, comprising Volume XX of the Proceedings, were issued in pamphlet form:

Revision of the Orthopteran Group Melanopli (Acridiidæ) with special reference to North American Forms, by Samuel Hubbard Scudder, pp. 1–421, 26 plates.

Notes on Cestode Parasites of Fishes, by Edwin Linton, pp. 423–456, 8 plates.

Preliminary Diagnoses of New Mammals of the Genera Lynx, Urocyon, Spilogale, and Mephitis, from the Mexican Boundary Line, by Edgar A. Mearns, pp. 457–461.

Description of a new Blenny-like Fish of the Genus Opisthocentrus, collected in Vulcano Bay, Port Mororan, Japan, by Nicolai Grebnitski, by Tarleton H. Bean and Barton A. Bean, pp. 463–464, 1 plate.

Description of a new Crustacean of the Genus Sphæroma from a Warm Spring in New Mexico, by Harriet Richardson, pp. 465–466.

Preliminary Diagnoses of New Mammals of the Genera Mephitis, Dorcelaphus, and Dicotyles, from the Mexican Border of the United States, by Edgar A. Mearns, pp. 467–471.

New Species of Coleoptera of the Family Chrysomelidæ, with a Short Review of the Tribe Chlamydini, by Martin L. Linell, pp. 473–485.

Notes on a Collectian of Fishes from the Colorado Basin in Arizona, by Charles Henry Gilbert and Norman Bishop Scofield, pp. 487–499, 4 plates.

Preliminary Diagnoses of New Mammals of the Genera Sciurus, Castor, Neotoma, and Sigmodon, from the Mexican Border of the United States, by Edgar A. Mearns, pp. 501–505.

Notes on Trematode Parasites of Fishes, by Edwin Linton, pp. 507–548, 15 plates.

A list of the birds known to inhabit the Philippine and Palawan Islands, showing their distribution within the limits of the two groups, by Dean C. Worcester and Frank S. Bourns, pp. 549–566.

Notes on the Distribution of Philippine Birds, by Dean C. Worcester, pp. 567–625, 1 map and 6 distribution charts.

Supplement to the Annotated Catalogue of the Published Writings of Charles Abiathar White, 1886–1897, by Timothy W. Stanton, pp. 627–642.

Observations on the Astacidæ in the United States National Museum and in the Museum of Comparative Zoology, with Descriptions of New Species, by Walter Faxon, pp. 643–694, 9 plates.

A Revision of the Tropical African Diplopoda of the Family Strongylosomatidæ, by O. F. Cook, pp. 695–708.

American Leaf-Hoppers of the Subfamily Typhlocybinæ, by Clarence P. Gillette, pp. 709–773.

A Revision of the Deep-Water Mollusca of the Atlantic Coast of North America, with Descriptions of New Genera and Species, Part I, Bivalvia, by Addison E. Verrill and Katherine J. Bush, pp. 775–901, 27 plates.

The Museum also published Part L of Bulletin 39, containing instructions for the collection of scale insects, by Prof. T. D. A. Cockerell, and Circular 48, relating to the collection and preservation of the bones and teeth of the mastodon and mammoth.

VII. BUREAU OF ETHNOLOGY REPORTS.

No completed volumes of the Reports of the Bureau of American Ethnology were issued during the year. The seventeenth report was sent to the Public Printer on July 6, 1897, and typesetting was practically completed during the fiscal year. This report contains memoirs on The Seri Indians, Calendar History of the Kiowa Indians, Navaho House, and Archæological Expedition in Arizona in 1895.

The eighteenth report was sent to the Public Printer on March 11, 1898, and contains papers on The Eskimo About Bering Strait, and Indian Land Cessions in the United States.

VIII. ANNUAL REPORTS OF THE AMERICAN HISTORICAL ASSOCIATION.

Annual Report of the American Historical Association for the year 1896, Washington, Government Printing Office, 1897. 8°, 2 vols. Vol. I, pp. 1313; Vol. II, pp. 442.

The first volume contains the proceedings of the Twelfth Annual Meeting, December 29–31, 1896, by Herbert B. Adams, Secretary; report of the Treasurer, list of Committees, necrology, and the following papers: Inaugural Address of Richard S. Storrs, President of the Association, on Contributions made to our National Development by Plain Men; Leopold von Ranke, by E. G. Bourne; The Journals and Papers of the Continental Congress, by Herbert Friedenwald; The Anti-rent Episode in the State of New York, by David Murray; A Know-Nothing Legislature, by G. H. Haynes; Peale's Original Whole-Length Portrait of Washington, by Charles Henry Hart; Political Science and History, by J. W. Burgess; The Use of History made by the Framers of the Constitution, by E. G. Bourne; Schemes for Episcopal Control in the Colonies, by Arthur Lyon Cross; The Teaching of History, by Herbert B. Adams; The Teaching of European History in the College, by James Harvey Robinson; The West as a Field for Historical Study, by Frederick J. Turner; A Plea for the Study of Votes in Congress, by Orin Grant Libby; The Northern Lake Frontier during the Civil War, by J. M. Callahan; Langdon Cheves and the United States Bank, by Louisa P. Haskell; The Influence of the American Revolution on England's Government of her Colonies, by George B. Adams; The Government of Federal Territories in Europe, by Edmund C. Burnett; The Value of Maps in Boundary Disputes, by P. Lee Phillips; Report of the Historical Manuscripts Commission of the American Historical Association, containing Guides to Archives, Letters of Phineas Bond, Letters to the Duke de Mirepoix, Letters of Stephen Higginson, Diary of Edward Hooker, and Clark-Genet Correspondence; Public Documents of Early Congresses, by Gen. A. W. Greely; List of Books Relating to America in the Register of the London Company of Stationers from 1562 to 1638, by P. Lee Phillips; An Essay toward a Bibliography of Leopold von Ranke, by William Price.

The second volume is an exhaustive work on the Proposed Amendments to the Constitution of the United States during the Frst Century of its Existence, by Herman V. Ames.

The report of the Association for the year 1897 was transmitted to the Public Printer on June 9, 1898, and was partly in type before the fiscal year ended. This report contains the proceedings of the Thirteenth Annual Meeting December 28–30, 1897, by Herbert B. Adams, Secretary; report of the Treasurer; list of Committees and Officers; Inaugural Address of James Schouler, President, on a New Federal Convention; John Cabot and the Study of Sources, by George Parker Winship; To What extent may Undergraduate Students of History be Trained in the use of the Sources, by James A. Woodburn; The Functions of State and Local Historical Societies, with respect to Research and Publication, by J. F. Jameson; State-Supported Historical Societies and their Functions, by Reuben Gold Thwaites; History in the German Gymnasia, by Lucy Maynard Salmon; Discussion of the Relation of the Teaching of Economic History to the Teaching of Political Economy, by Henry B. Gardner, George W. Knight, and Henry R. Seager; Introduction to Southern Economic History: The Land System, by James Curtis Ballagh; Mirabeau and Calonne in 1785, by Fred Morrow Fling: Some of the Consequences of the Louisiana Purchase, by Samuel M. Davis; National Politics and the Admission of Iowa into the Union, by James A. James; Spanish Policy in Mississippi after the Treaty of San Lorenzo, by Franklin C. Riley; Cuba and Anglo-American Relations, by James Morton Callahan; The Diplomacy of the United States in regard to Cuba, by John H. Latané; The Protestant Revolution in Maryland, by Bernard C. Steiner; European Blue Laws, by John Martin Vincent; The Founding of the German Reformed Church in America by the Dutch, by James I. Good; First Suggestions of a National Observatory, 1825, by James C. Courtenay; Second Annual Report of the Historical Manuscripts Commission of the American Historical Association, containing list of Sessions and Journals of Colonial Assemblies, Letters of Phineas Bond (concluded), and Mangourit Correspondence; Guiana and Venezuela Cartography, by P. Lee Phillips; and Bibliography of Alabama, by Thomas M. Owen.

Respectfully submitted.

A. Howard Clark, *Editor*.

Mr. S. P. Langley,
Secretary of the Smithsonian Institution.

Appendix VIII.

REPORT ON THE TENNESSEE CENTENNIAL EXPOSITION, NASHVILLE, TENN., 1897.

Sir: I have the honor to submit the following report on the exhibit of the Smithsonian Institution, the National Museum, and other bureaus under the direction of the Institution, at the Tennessee Centennial Exposition.

In an act of Congress approved December 22, 1896, provision was made for participation in the exposition by the Executive Departments of the Government, the Smithsonian Institution and National Museum, and the United States Fish Commission.[1]

The exhibit of the Smithsonian Institution was intended to illustrate as fully as possible the character and scope of the work accomplished by the Institution and the several bureaus under its direction. For obvious reasons the activities of the National Museum could be represented in a more complete manner than was possible in the case of the Institution proper, or of any of the other bureaus under its direction. Almost every department of the National Museum furnished an exhibit, although some of the latter were much fuller than others.

The space assigned to the Institution was in the northeast corner of the Government building and comprised about 5,000 square feet. There was a frontage of 101 feet on the main aisle running east and west, with a width of 48 feet. At the west end of the space there was a series of alcoves, but otherwise the cases were placed in rows. Two short aisles led from the main aisle, at right angles with it, their inner ends joining an aisle which ran parallel to the main thoroughfare.

Against the east wall were installed the exhibits of the Institution proper, the Bureau of International Exchanges, the National Zoological Park, and the Astro-Physical Observatory.

In the center of the north hall was the exhibit of the Bureau of Ethnology. The remainder of the space was devoted to the collections of the National Museum.

In the windows were transparencies showing the seal of the Smithsonian Institution; the Smithsonian and National Museum buildings, with interior views of each; four views of the National Zoological Park; four geological subjects—an Australian coral reef, the Yosemite Valley, the Devil's Tower in Wyoming, and the Mammoth Hot Springs; four zoological subjects—a deep-sea fish, a cuttlefish, a hydroid, and sea-lilies; and eight ethnological subjects.

SMITHSONIAN INSTITUTION.

A complete set of the publications of the Institution, including those of the Bureau of Ethnology and the National Museum, formed one of the principal features of the exhibit. Adjoining this was an exhibit of title-pages and some of the more important illustrations in these publications.

Portraits of James Smithson, the founder of the Institution; of Secretaries Joseph Henry, Spencer Fullerton Baird, and Samuel Pierpont Langley, and of the late George Brown Goode, Assistant Secretary, were hung upon the wall.

In a separate case was displayed a photographic portrait of Thomas G. Hodgkins,

[1] The act referred to is given in full in the Report of the Smithsonian Institution for 1897, Pages XLV–XLVII.

together with examples of the medals awarded in 1895 to writers of essays competing for the Hodgkins fund prizes, and copies of the prize memoirs which had been published.

On the wall adjacent was a cast of the memorial tablet which had recently been placed, by order of the Board of Regents, on the tomb of Smithson, in Genoa, Italy.

Two enlarged photographs of Secretary Langley's aerodrome (flying machine), which twice flew over one-half mile on May 6, 1896, near Quantico, Va., were also exhibited. The photographs were of different views of the machine, and two-fifths its actual size.

BUREAU OF AMERICAN ETHNOLOGY.

The exhibit of this Bureau consisted of one-half of a Kiowa camping circle in miniature, the material for which was collected by Mr. James Mooney, of the Bureau.

The entire exhibit was the work of Kiowa Indians, the insignia emblazoned on the tepees and shields being executed, almost without exception, by those having an inherited right to bear them. This aboriginal tribe is now the only representative of a distinct stock or linguistic family of priscan people.

Owing to the restricted space available, the skin tents were reduced from 16 or 18 feet in height to about 2½ feet, while their number was reduced from about 150 (half of the 300 or more tents forming the entire circle) to 25, exclusive of the ceremonial lodges within the circle.

The exhibit was prepared and installed by Mr. James Mooney, under the direction of Mr. W J McGee.

NATIONAL ZOOLOGICAL PARK.

The extent and topography of the National Zoological Park were well shown in the model exhibited, on which the buildings, roadways, and bridges, and the woods, creek, and other natural features were faithfully represented.

In the windows along the Smithsonian section were several transparencies, including one of the carnivora house, one of the bridge, and one of a buffalo. There were also exhibited three water-color paintings and one drawing, the work of Mr. Glenn Brown, illustrating other attractive features of the park.

BUREAU OF INTERNATIONAL EXCHANGES.

A principal exhibit of this bureau was a complete set of the publications of the United States Government for one year, being one of the fifty sets, such as are distributed annually by the bureau to libraries throughout the world.

On the wall was a large map showing the geographical distribution of the correspondents of the Institution, 24,000 in number, as entered on the registers of the Bureau.

Near the map was a diagram illustrating the number of publications, including books and pamphlets interchanged between each State and Territory in the United States and foreign countries during the ten years preceding January 1, 1896.

The exhibit was prepared by Mr. W. I. Adams.

ASTRO-PHYSICAL OBSERVATORY.

The exhibit of the observatory consisted of photographs of the exterior and interior of the building located on the Smithsonian grounds, and of the principal instruments, such as the siderostat, galvanometer, spectrometer, and water-jacketed bolometer and rheostat. Enlarged photographs of portions of the spectrum of the sun were also exhibited. With these objects was a bolometer, or electrical thermometer, of extreme delicacy, the invention of Mr. S. P. Langley.

NATIONAL MUSEUM.

As already stated, the exhibit of the National Museum was of much greater extent than that of any of the other Smithsonian bureaus.

Two objects were kept in mind in its organization:

(1) To show as far as possible the extensive scope of the Museum.

(2) To indicate the manner in which the collections are arranged, labeled, and displayed in the Museum building in Washington.

In carrying out the first idea it was necessary to exhibit a small number of objects from many different kinds of collections, which had a certain disadvantage in a space so comparatively small, as the bringing into close proximity of objects not nearly related could not be avoided. It was impracticable, on account of the limited space, to show all the different classes of objects in the Museum.

The greater portion of the labels, cases, stands, bases, backgrounds, and other fittings and furniture were from the regular stock of the Museum, although a few methods of installation entirely novel were introduced for the first time in connection with the exhibit.

Department of mammals.—This department exhibited in two cases a representation of the interesting order of mammals known as the lemurs—monkey-like animals—especially characteristic of the island of Madagascar, but having representatives on the continents of Africa and Asia. The group comprises about 35 species, of which 18 were shown, among them the especially remarkable aye-aye, so long a puzzle to zoologists on account of peculiarities of its structure, and one of the Tarsiers (*Tarsius spectrum*) which are notable for the great size of their eyes.

On the walls were casts of heads of two genera of the so-called Ziphioid whales, *Mesoplodon* and *Ziphius;* of the Pygmy Sperm Whale, *Kogia*, and of the New Zealand Whale, *Neobalæna*, the smallest and rarest of the true whalebone whales.

The exhibit was prepared and installed, under the direction of the curator of mammals, by Mr. William Palmer.

Department of birds.—The birds were exhibited in four cases on the main aisle, one of which contained a representation of the parrots, and the other a faunal collection from British Guiana, South America.

Parrots.—This collection comprised 124 specimens, representing about 100 species, or about one-fifth of those that are known. All the subfamilies were represented and the more important genera, so that the collection was a fair exhibit of the group.

Birds of Guiana.—This exhibit represented a tropical bird fauna notable for bright colors and peculiar forms. It was, of course, very incomplete, as it was impracticable to show all of the eight hundred or nine hundred species which are found in Guiana.

The exhibit was prepared by Mr. Robert Ridgway, assisted by Mr. C. W. Richmond.

Department of reptiles and batrachians.—The exhibit of this department consisted of a group of the poisonous snakes of the United States, cast in plaster, and a similar group of the fresh-water and land tortoises of North America. A cast of the head of a logger-head turtle was also included. The specimens were brought together from widely separated localities.

The following species were represented:

Poisonous Snakes of the United States.—Diamond rattlesnake, *Crotalus adamanteus*, Southeastern States.

Banded rattlesnake, *Crotalus horridus*, Eastern States, south to Florida and the the Mexican Gulf, west to Kansas.

Prairie rattlesnake, *Crotalus confluentus*, Great Plains.

Western diamond rattlesnake, *Crotalus atrox*, Southern United States, from Texas to the Gulf of California.

Southern ground rattlesnake, *Sistrurus miliarius*, Southeastern States.
Copperhead, *Agkistrodon contortrix*, Eastern and Southern States.

The group of tortoises included the following species:

Gopher, *Gopherus polyphemus*, Florida.
Agassiz's gopher, *Gopherus agassizii*, Arizona and Southern California.
Berlandier's gopher, *Gopherus berlandieri*, western Texas.
Box tortoise, *Terrapene carolina*, Eastern States.
Western Box tortoise, *Terrapene ornata*, Central States.
Blanding's tortoise, *Emydoidea blandingii*, Massachusetts to northern Illinois.
Wood tortoise, *Clemmys marmorata*, California.
Elegant terrapin, *Trachemys elegans*, Central and Southern States.
Yellow-bellied terrapin, *Trachemys scripta*, Southeastern States.
Florida terrapin, *Pseudemys floridana*, Florida.
Neat terrapin, *Pseudemys concinna*, North Carolina to Texas.
Red-bellied terrapin, *Pseudemys rubriventris*, Middle Atlantic States.
Painted turtle, *Chrysemys picta*, Eastern States.
Diamond-back terrapin, *Malaclemys centrata*, Atlantic and Gulf coasts.
Baur's terrapin, *Graptemys pulchra*, Southeastern States.
Snapping turtle, *Chelydra serpentina*, North America, east of the Rocky Mountains.
Mud turtle, *Kinosternon pensilvanicum*, east of the Rocky Mountains.
Soft-shelled turtle, *Platypeltis ferox*, Florida.

Department of fishes.—This department showed a selected series of fishes of the deep sea, which formed the basis of the comprehensive work on "Oceanic Ichthyology," by the late Dr. G. Brown Goode and Dr. Tarleton H. Bean, published a few months previous to the Exposition as a special bulletin of the Museum.

The exhibit was supplemented by a small number of casts of North American fishes painted in life colors and forming part of an extensive series in the Museum.

The following fishes were represented by casts:

Calico bass, *Pomoxys sparoides*.
Sunfish, *Lepomis pallidus*.
Dolphin, *Coryphæna hippurus*.
Mangrove snapper, *Lutjanus stearnsi*.
Sea robin, *Prionotus evolans*.
Red-mouth grunt, *Hæmulon arcuatum*.
Cagon de lo Alto, *Rhomboplites aurorubens*.
Grouper, *Epinephelus drummond-hayi*.
Scup, *Stenotomus chrysops*.
Hogfish, *Lachnolæmus maximus*.
Parrot fish, *Pseudoscarus guacamaia*.
Rosy rockfish, *Helicolenus maderensis*.
Brook trout, *Salvelinus fontinalis*.
Cavalla, *Caranx hippos*.
Sucking fish, *Echeneis naucrates*.
Eelpout, *Zoarces anguillaris*.
Four-spotted flounder, *Paralichthys oblongus*.
Cowfish, *Ostracion quadricorne*.

The exhibit was arranged by Mr. Barton A. Bean.

Department of mollusks.—This exhibit was in two table cases and represented, as far as space permitted, the families of mollusks and brachiopods. It also contained illustrations of the utilization of materials derived from mollusks. Each family was represented by one or more species, excepting those in which there is no solid shell and which therefore could not be exhibited in a dry condition.

The classification used was that adopted in the national collection.

Utilization of mollusks.—This series included pearls, cameo shells of various sorts, specimens illustrating the formation of pearl in the shell, both fresh-water and marine pearl mussels deprived of their outer coating so as to show the pearly substratum, and manufactured articles, such as buttons and other objects. made from pearl-bearing shells, of which specimens both in the natural condition and decorticated—so as to show the shelly layer—and in the manufactured state, were exhibited.

Byssus of the "wing-shell."—A somewhat rare object was a glove resembling silk woven by the nuns of Naples from the silky byssus of the pinna, or "wing-shell," of the Mediterranean.

In one of the windows was a transparency of a cuttle fish, *Octopus verrucosus*, and suspended from the ceiling were life-size models of an octopus and of the giant squid, *Architeuthis harveyi*.

The selections for the exhibit were made by Mr. C. T. Simpson under the direction of Mr. W. H. Dall.

Department of insects.—This display occupied one side of two cases, and was included in sixteen trays. It was, of course, very far from complete, either as an exhibit of insects or as an illustration of the wealth of material in the entomological collections of the Museum. Two different series were, however, shown—a systematic series, and a series illustrating protective and aggressive resemblance and mimicry, (the imitation, by insects, in form and color, or both, of objects met with in their surroundings, and the imitation of the form and color of other insects).

Systematic series.—This series was included in twelve trays, and represented the more conspicuous insects of Tennessee and neighboring States, arranged according to their scientific classification. The Lepidoptera was more fully represented than any other order, since the species are generally large and showy, and well adapted for exhibition purposes. Six trays were devoted to this order. The modern orders corresponding to the older order Neuroptera were exhibited in one tray, and the remaining five trays were taken up with the orders Hymenoptera, Coleoptera, Hemiptera, Diptera, and Orthoptera. All of the smaller species were omitted, as they could be represented adequately only by means of enlarged drawings or models for the preparation of which funds could not be provided.

Protective and aggressive resemblance and mimicry.—This series occupied four trays and was divided into seven groups. It consisted of specimens illustrating the following phases of resemblance and mimicry:

(1) General protective resemblance (insects having a general resemblance in color to their surroundings).

(2) Special protective resemblance (insects resembling objects in their surroundings, both in form and color).

(3) General aggressive resemblance (carnivorous insects having a general resemblance to their surroundings in color, thereby enabling them to more easily approach their prey).

(4) Special aggressive resemblance (carnivorous insects resembling in form and color some special object in their surroundings).

(5) Protective mimicry (insects which for their own protection mimic other insects having some special means of defense, such as a sting or noxious odor, and which for that reason are avoided by birds, lizards, etc.).

(6) Aggressive mimicry (insects which resemble other insects in order to approach or cohabit with them, either preying directly upon them or as parasites upon their larvæ).

(7) Warning colors (insects which are already protected by a sting or in some other way, but which have, in addition, some bright or conspicuous color, in order to warn insectivorous animals from attacking them).

The collections were arranged by the late Mr. Martin L. Linell, under the direction of Dr. L. O. Howard.

Department of marine invertebrates.—This department has to do chiefly with the many groups of invertebrate animals that inhabit seas and rivers, with the exception of mollusks, which on account of their great variety are placed in a separate department. The groups selected for exhibition were the echinoderms (or sea urchins and their allies), the corals, and the sponges. A representative series of each class was shown.

The sponges or Porifera were principally from the East Indian region, and exhibited in a wide range those species which, although graceful in form, are not used for commercial purposes.

The corals were also chiefly from the Indo-Pacific. The diversity of form was the prominent feature.

The echinoderms were arranged more systematically than was found practicable with the other invertebrates of this department.

Among the transparencies in the windows were those of a sea-lily, *Pentacrinus decorus*, hydroid, *Acanthocladium huxleyi*, and an enlargement of a specimen of *Globigerina bulloides* (a species of foraminifer).

The exhibit was prepared and installed by Mr. James E. Benedict.

Department of comparative anatomy.—From this department two series were selected, one showing the modification of the limbs of animals for different modes of life, and another representing the structure of the human brain.

Modification of limbs.—A considerable series of specimens was exhibited, showing the general plan of the limbs in vertebrates and the special modifications by which they are adapted for walking, climbing, swimming, and flying.

The structure and development of the human brain.—The structure, proportions, and development of the human brain were illustrated by series of models showing various stages in the growth of the brain in the embryo, and, on a large scale, details of its structure in the adult. A number of diagrammatic models showed the comparative bulk of the brain of the male and female, the least amount of brain compatible with life, the proportionate amounts of gray and white matter, etc. These models were supplemented by a small series of skulls, illustrating the diversity of form found in various races of man.

Crocodiles.—Above the cases were placed a skeleton of the gavial or narrow-beaked crocodile of the Ganges, erroneously supposed to be a "man-eater," and a very large skull of the true man-eating crocodile, *Crocodilus porosus*.

The exhibit was prepared and arranged by Mr. F. A. Lucas.

Department of paleontology.—This exhibit occupied one side of three cases, and was intended to show the character of the collections in the department and the manner in which they are arranged, mounted, and labeled. Only the best-preserved specimens, from which the adhering rock had been removed by careful working with tools and chemicals, were exhibited. The trilobites and crinoids were mounted on encaustic tiles, in preference to wood, paper, or slate tablets.

The groups of the fossils represented were—

(1) A collection of fossil fishes from the very ancient *Bothriolepis* to modern bony fishes, like the shad.

(2) A synoptic collection of trilobites—a group of crab-like animals—of which all forms became extinct subsequent to the coal period. This collection was prepared to show the structure, geological development, and grouping of the various forms into families and orders.

(3) A synoptic collection of fossil crinoids or "sea-lilies."

The specimens were selected and grouped by Mr. Charles Schuchert.

Department of geology.—In two cases there was exhibited a collection illustrating the occurrence and association of gold and silver in nature, thus described by Prof. George P. Merrill.

"The exhibition begins with specimens showing both the native metals and their compounds in the condition of greatest natural purity. This is followed by a series of the same compounds with their characteristic associations, but in which the metal-bearing portions are still plainly evident, and this in turn by a third series showing selected types of ores as mined, but in which, as a rule, the metal or its compounds are scarcely discernible.

"In the series as exhibited attention is called, first, to the native gold—that is, the gold found in the metallic state in nature, as displayed in the form of nuggets, leaf gold, wire gold, and gold dust from various localities; second, to the compounds of gold with silver, tellurium, antimony, and sulphur, as shown in the minerals petzite, sylvanite, krennerite, and nagyagite; third, to the occurrence of the native metal with its associates, either as dust or nuggets, in sand and gravel, or impregnating quartz, slate, calcite, and other minerals forming the characteristic gangue, and lastly, to the series of gold ores, representing the metal-bearing rocks as usually mined and which, while, as above noted, show no trace, on casual inspection, of the precious metal, nevertheless contain it in sufficient amount to render its extraction by chemical or mechanical means a profitable industry.

"The silver-bearing series is arranged in a similar manner. It is to be noted that while gold is common in deposit of sand and gravel as placer gold, silver very rarely occurs in this form, and is represented here only by the silver-bearing sandstone from Washington County, Utah. Native silver in the form of wire or moss silver is, however, comparatively common, as shown in the specimens from Mexico and Saxony. Some of the silver-bearing compounds are of great beauty, as illustrated in the ruby silvers proustite and pyrargyrite."

In addition to the general series, a number of casts of exceptionally large and interesting nuggets of gold and silver was arrayed in a separate case. Each cast was accompanied by a descriptive label.

In the windows were transparencies, showing an Australian coral reef and views from the Mammoth Hot Springs, the Yosemite Valley, and the Devil's Tower, in Wyoming.

The specimens were selected and prepared by Prof. G. P. Merrill and installed by Mr. W. H. Newhall.

Department of minerals.—The exhibit of this department consisted of a series of about five hundred specimens, selected and labeled to illustrate the several properties or characters of minerals. The general plan of arrangement will be understood from the synopsis here presented.

(1) Chemical mineralogy: Types of minerals. Variation in composition. Relation of water to composition. Relation of composition to physical properties.

(2) Physical mineralogy: The crystal. The crystallographic axes. Crystal systems. Compound crystals. Imperfections of crystals. Crystalline aggregates. Pleomorphs. Isomorphs. Pseudomorphs, (*a*) by substitution; (*b*) by deposition; (*c*) by alteration. Cleavage. Fracture. Tenacity. Hardness. Color, (*a*) essential color; (*b*) nonessential color; (*c*) varieties of color. Luster. Diaphaneity. Fusibility.

Special attention was paid to the order of arrangement. The several specimens illustrating the chemical and physical properties of minerals were arranged to be studied from left to right, beginning with the upper left-hand corner and regarding each quadrant of the case as a unit.

Chemical mineralogy, which treats of those properties relating to chemical composition or atomic structure of a mineral and the chemical relations of the several kinds of minerals, was illustrated by 184 specimens. Physical mineralogy, which treats of those properties relating to form or molecular structure of a mineral and the action of the various physical forces upon the several kinds of minerals, was illustrated by 315 specimens.

Department of ethnology.—The ethnological exhibit consisted of two parts:

(1) An exhibit of the home life and industries of the Eskimo.

(2) An exhibition of the domestic life and arts of the Pueblo region.

In the first group the most conspicuous object was a house similar in construction to those occupied by the natives of Norton Sound.

This exhibit was prepared under the direction of Mr. E. W. Nelson, and was built of logs set on end, the corner posts being the larger. Above these were placed series of logs growing shorter with each layer, a square smoke hole being left at the peak of the roof. The furniture of the house consisted of a bed made of driftwood, of a fireplace on the floor with a curious device for directing the draft and smoke out of the smoke hole, and a clay lamp for lighting the pipe and other like domestic purposes. In the house were the lay figures of a man and of a woman, in full native costume, the latter tending the fire, the former watching her movements and lighting his pipe. Around the different parts of the room were such furniture as would be found in a native hut. As the plan of this structure was given by one who had spent a long time in the country, the details were quite accurate.

Associated with this group and mounted in separate sliding-screen cases were shown a large number of objects connected with the life of the Eskimo.

Case No. 1, fronting the group, contained masks, carved from driftwood and ornamented with feathers, such as are used in the dramas of the Eskimo during the long winter season, when the sun has left the Arctic region. On the back of this same case were shown examples of the needlework of the Arctic tribes, including beaded work from Greenland, exhibiting the Scandinavian influence—a complete suit for a man, made of different furs cut in strips, which were inserted to produce various pleasing patterns; a full suit of man's clothing from Ungava, north of Labrador, made of reindeer skin, the hair being removed; a deerskin suit for winter wear, made from the skin of the caribou with the hair on.

Case No. 2 contained an exhibit of the various types of basketry in Alaska and on the Pacific coast of America southward to the borders of the United States.

Case No. 3 was devoted to the work of the Eskimo and their neighbors, in skins and other animal products, such as workbags for women, tobacco pouches, tool bags, belts, made from the skins of seals and other animals, with or without the fur, and also from the intestines of the seal, sewed with sinew and decorated with feathers and worsteds.

Case No. 4 illustrated the traveling devices of the Eskimo. Snowshoes of coarse texture used by the tribes farthest north and in out-of-the-way places, and those with footing of sinew, finely twisted and woven, similar to those in use by the Athapascan tribes in the neighborhood, were shown; also models of boats in two types, the kaiak, or hunting canoe, and the umiak, or woman's boat. There were also to be seen in this case the tools used by the Eskimo in digging in the ice and removing snow and broken ice.

On the opposite side to that in which the Eskimo material was installed was the Pueblo collection. The chief exhibit in this area was a group showing several Moki females grinding corn and making bread. (Case No. 5.) In association with this group of breadmakers were examples of the objects used in the industrial and social life of the Tusayan and other Pueblo people.

Case No. 6 was devoted to the display of the various kinds of weaving employed in the Pueblo region.

Case No. 7 contained examples of pottery from Pueblos in New Mexico and Arizona, and showed a variety of shapes, colors, and decorations in cups, bowls, vases, and animal forms.

Case No. 8. On one side was exhibited (in comparison and contrast with the textile art of the Pueblo tribes) the bead work and substitutes for textile work among tribes on the eastern side of the Rocky Mountains, including work on soft buckskin, on the surface of hard leather, on flannel and other cloths of European manufacture, and finally beadwork forming part of the textile art; that is, in which the beads are not laid on the surface of another substance, but form a part of the fabric, so that the same figure is shown on both sides, as in a piece of stained glass.

In front of this case was arranged a collection of Moki gods and dolls and headdresses connected with their religious services; also sacred blankets and wrappings, wands and shields, associated with the intricate and dramatic worship of these Pueblo tribes.

On the wall above these exhibits were to be seen ornamental shields of wood on which were set large collections of Eskimo and African weapons, ornamental paddles of the North Pacific coast Indians, and other decorative objects.

In addition, an ethnological exhibit installed in thirty-two unit boxes, was displayed in the annex to the woman's building. Each contained a typical example of woman's work in America, Africa, Polynesia, and a few from other regions.

These examples of woman's work related to the arts of food gathering, preparing, and serving; to clothing in its various forms derived from the vegetable and animal kingdoms, and of the furniture of the habitation. In addition to these there were exhibited the primitive ideas of women connected with form and color in decoration.

In front of these cases, were three cases in which were three American Indian women in costume: (1) An Eskimo woman of Bathurst, the whole costume being made of reindeer skin, trimmed with the fur of small animals; (2) A Kiowa woman in native costume of buckskin, colored green, and carrying on her back a cradle or papoose frame, in which was shown a child securely wrapped; (3) A Piute woman from the great interior basin, gathering seeds from the wild grasses, to be subsequently ground and made into bread.

In addition to the specimens and lay-figures shown, there was, in connection with the ethnological exhibit, a collection of ethnographic transparencies, which aided in the understanding of the specimens in relation to their environments.

The exhibit was prepared by Prof. O. T. Mason, and installed by Mr. T. W. Sweeny.

Department of prehistoric anthropology.—The exhibit of this department was confined to a display of prehistoric objects from foreign countries. This restriction in the scope of the exhibit was made in the belief that the weapons, implements, and ornaments found in the Tennessee Valley and other sections of the United States, would be amply illustrated in the various local exhibits of prehistoric objects.

The Paleolithic period was represented by specimens from a large portion of the Eastern Hemisphere—England, France, Spain, Italy, Egypt, Hindustan, and other countries.

The Neolithic period was represented by different implements, principally of polished stone, from great areas. They were classified chiefly according to function.

The distribution of nucleii (or cores), flakes, and hammerstones, polished stone hatchets, scrapers, arrowheads and spearheads, and similar implements was shown to be world-wide. Special attention was called to the similarity of the polished stone hatchets from distant and widely separated countries throughout the world.

An entire case was devoted to a display of objects belonging to the bronze age. These began with the most primitive implements, as the plain hatchet, and ultimately included many other weapons, implements, utensils, and ornaments of later date. Among these were hatchets, swords, daggers, knives, sickles, fishhooks, household utensils, mirrors, combs, thimbles, bracelets, fibulas, rings, pins, objects and ornaments of dress and for the boudoir.

The collection was selected and arranged by Dr. Thomas Wilson.

Department of oriental antiquities and religious ceremonials.—The exhibit of this department consisted of objects intended to illustrate Brahmanism and Buddhism (the principal religions of Eastern Asia), Mohammedanism, the literary history of the Bible, and the religious ceremonials of the Jews.

Brahmanism was represented by a collection of images of the principal divinities and by various implements and paraphernalia illustrative of the religious worship, the ascetic life of devotees, and the institution of caste, which plays such an important part in the religious and social life of India.

Buddhism was represented by several images of Buddha and of Buddhist saints, and by a collection of musical instruments and other objects used by the Buddhists in their religious worship.

The history of the Bible as a book was illustrated by a collection of Bibles, which included manuscripts and old and rare editions of the original texts, as well as of the most important ancient and modern translations of the Scriptures. The collection thus afforded an interest not only to biblical knowledge, but also to the study of paleography and literary history.

The Jewish religious ceremonials were represented by a collection of modern objects used by the Jews in their religious rites, which have their origin in and are based upon biblical ordinances.

The exhibit was prepared and installed by Dr. I. M. Casanowicz, under the direction of Dr. Cyrus Adler.

Section of technological collections.—Owing to the geographical location of Nashville, it was thought that a presentation of some of the early methods of transportation in the Southern States might be of special interest.

A small series of models was selected to show the development in transportation from its beginning in colonial days, when the sledge was almost the only method of locomotion, to the introduction of the first railroad train in the Southern United States, which ran on the South Carolina Railroad in 1831.

A rigged model of the *Savannah*, the first steamship to cross the Atlantic Ocean, was also included in this exhibit. The *Savannah* sailed from the city of that name, one of the most important ports in the Southern States, in the year 1819.

From the section of naval architecture was selected a model of a full-rigged ship. In order to make plain to the visitors the nomenclature of the ropes, spars, sails, etc., over four hundred labels were attached to as many different parts of the model.

From the electrical collection was sent a series representing the early instruments of Franklin, Henry, Morse, Vail, and Page, and illustrating the development of the motor and telegraph from the beginning of knowledge concerning static electricity to the more recent discoveries in electro-magnetism. A full-sized model of the large electro-magnet which was constructed by Joseph Henry in 1831 for Yale College was placed on the case containing the electrical collection.

The selections for the exhibit were made by Mr. J. E. Watkins.

Section of historical relics, coins, and medals.—The collection of coins and medals was exhibited in two table cases, and included—

(1) The principal coins in use in the North American colonies from 1652 to the establishment of the United States Mint in 1793, and types of the later coinage of the country.

(2) Medals commemorative of events in the colonial history of the country during the war of the Revolution and the war of 1812.

(3) Medallic portraits of the Presidents of the United States.

Among the most interesting coins shown were the "pine and oak tree" shillings of 1652, the "Mark Newby" penny, the "Rosa Americana" penny, the Continental dollar of 1776, and the copper coins of Massachusetts, Vermont, Connecticut, New Jersey, and other colonies, prior to coinage by the Mint.

There were also shown specimens of the North Carolina and Georgia private gold coinage of 1830 to 1840, of the Mormon gold coins of 1849, and some shell money, or "wampum," which was given a legal value in New England in 1637.

A spinning wheel and distaff which was used during the period of the war of the Revolution was exhibited in the History building.

The collection was selected and arranged by Mr. A. Howard Clark.

Section of materia medica.—Two series of specimens were sent from the extensive collection in the section of materia medica, the first consisting of samples of natural and cultivated cinchona barks and their products, and the second showing the commercial varieties and the alkaloids of opium.

The exhibit was prepared by Dr. J. M. Flint, U. S. N.

Department of arts and industries.—This department exhibited an attractive collection representing animal form in pottery, including the principal wares of Japan, and selections from Prussia, Saxony, Copenhagen, Denmark, and France.

Exhibit of laces.—A collection of specimens of network and embroidery, illustrating the various epochs of lace making, was exhibited in the annex to the Woman's building, by Dr. Thomas Wilson. The collection comprised about 1,000 specimens and may be classified under the following general divisions:

(1) Prehistoric: Implements for, and specimens of, sewing, weaving, embroidering, and tapestry making.

(2) Prior to 1550 A. D., anterior to lace making: Knotted net, darned work, drawn work, cut work.

(3) From 1550 A. D.: Reticella, point coupe, point lace, and bobbin lace of Venice, Milan, Genoa, Flanders, France, and England.

(4) Modern laces.

(5) Series showing process of manufacture of point and bobbin lace, needles, thread, cushions, bobbins, etc.

Mr. W. V. Cox, chief clerk of the National Museum, was in immediate charge of the entire exhibits of the Smithsonian Institution and National Museum.

Credit is due to Mr. J. S. Goldsmith and Mr. C. A. Steuart for their efficient supervision of the mechanical operations connected with the preparation and installation of the collections.

The amount appropriated by Congress for the Government exhibit was $100,000, and for the Government building $30,000. The sum allotted to the Institution and Museum was $16,200, the actual cost being $16,073.61, as shown in the following statement:

Services	$7,225.17
Expert services in preparation and repair of models, transparencies, charts, specimens, etc	888.95
Travel	1,015.26
Subsistence	803.30
Freight	738.19
Cartage and freight handling	77.18
Expressage	168.35
Exhibition cases, frames, etc	314.00
Lumber and millwork	673.55
Hardware, tools, etc	124.89
Glass, paints, brushes, etc	1,320.99
Supplies, preparator's material, etc	301.50
Packing material	163.40
Apparatus, specimens, etc	2,157.75
Decoration, flags, etc	66.25
Office expenses	34.88
Total	16,073.61

Respectfully submitted.

FREDERICK W. TRUE,
Representative Smithsonian Institution and National Museum.

Mr. S. P. LANGLEY,
Secretary of the Smithsonian Institution.

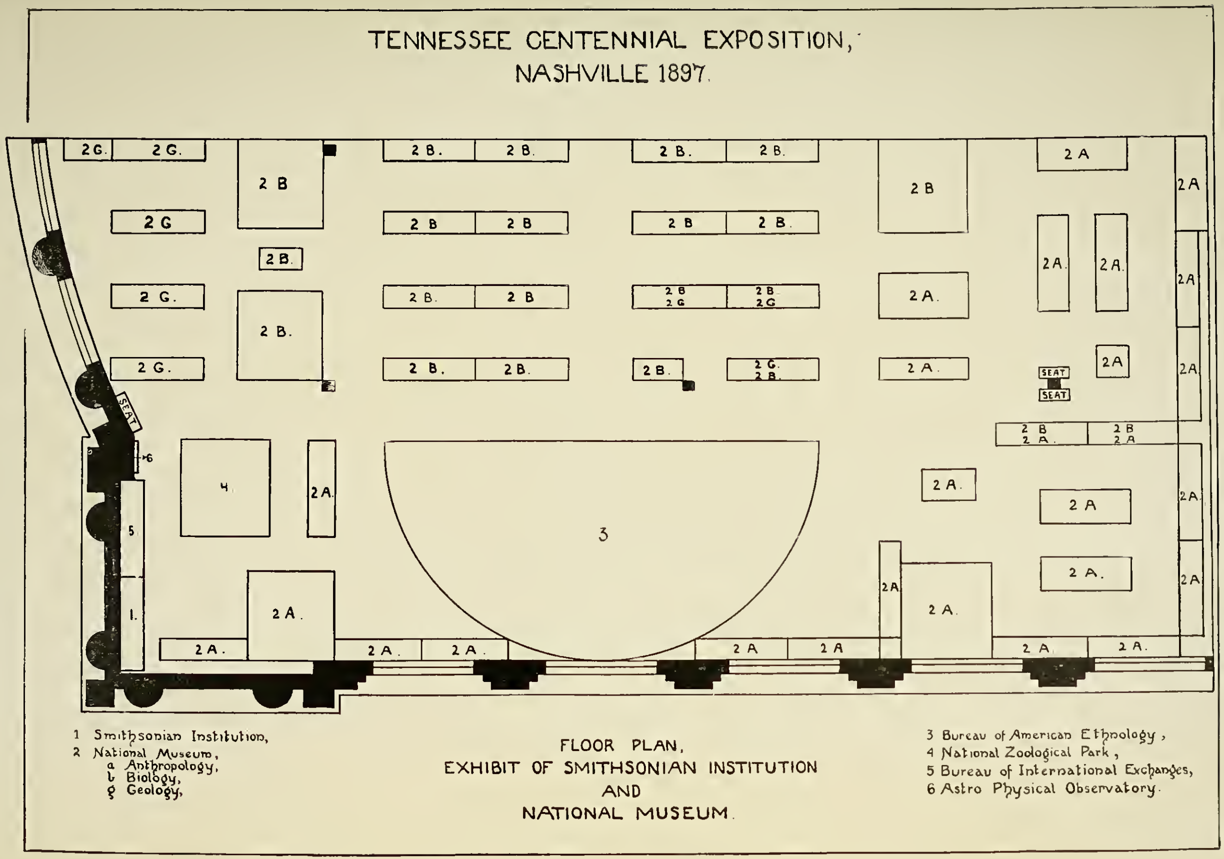


Exhibit of Smithsonian Institution and National Museum at Nashville Exposition, 1897.

GENERAL APPENDIX

TO THE

SMITHSONIAN REPORT FOR 1898.

ADVERTISEMENT.

The object of the GENERAL APPENDIX to the Annual Report of the Smithsonian Institution is to furnish brief accounts of scientific discovery in particular directions; reports of investigations made by collaborators of the Institution; and memoirs of a general character or on special topics that are of interest or value to the numerous correspondents of the Institution.

It has been a prominent object of the Board of Regents of the Smithsonian Institution, from a very early date, to enrich the annual report required of them by law with memoirs illustrating the more remarkable and important developments in physical and biological discovery, as well as showing the general character of the operations of the Institution; and this purpose has, during the greater part of its history, been carried out largely by the publication of such papers as would possess an interest to all attracted by scientific progress.

In 1880 the Secretary, induced in part by the discontinuance of an annual summary of progress which for thirty years previous had been issued by well-known private publishing firms, had prepared by competent collaborators a series of abstracts, showing concisely the prominent features of recent scientific progress in astronomy, geology, meteorology, physics, chemistry, mineralogy, botany, zoology, and anthropology. This latter plan was continued, though not altogether satisfactorily, down to and including the year 1888.

In the report for 1889 a return was made to the earlier method of presenting a miscellaneous selection of papers (some of them original) embracing a considerable range of scientific investigation and discussion. This method has been continued in the present report, for 1898.

RECENT PROGRESS ACCOMPLISHED BY AID OF PHOTOGRAPHY IN THE STUDY OF THE LUNAR SURFACE.[1]

By MM. LOEWY and PUISEUX.

(With three plates.)

I.—RÉSUMÉ OF THE PRINCIPAL QUESTIONS WHICH HAVE BEEN SUGGESTED BY LUNAR OBSERVATIONS.

Next to the sun, which furnishes us with heat and light, the moon, of the remaining celestial bodies, excites the greatest curiosity and suggests the greatest number of problems to investigators. The succession of its phases has furnished a unit of time, intermediate between that of the day and the year, which has been universally adopted. The eclipses which our satellite undergoes or occasions when it aligns itself with the earth and the sun have excited even the most undeveloped imaginations since antiquity. They still serve chronologists in verifying historical dates. Representing a source of important progress in physical astronomy, they give rise, several times in a century, to reunions and to the combined efforts of many astronomers. The rapidity of the apparent motion of the moon among the stars makes it very valuable for the determination of geographical coordinates; its ephemeris is an indispensable manual to travelers and to mariners. The researches of mathematicians have shown that the attraction of our satellite is the principal cause of the tides, and of precession and nutation, that is, changes in the direction of the earth's axis in space. The perturbations which the moon undergoes in its orbit teach us much in regard to the interior structure of our globe, of its ellipticity and of the fundamental constants of astronomy, such as the mass of the earth and the solar parallax. Its influence on the meteorological phenomena, strongly fixed in popular opinion, is still the object of persevering and impartial researches. Finally, by its relative proximity, the moon presents itself as an obliging stepping-stone when we wish to extend our investigations beyond the limits of the globe which has been assigned to us as our abode. Deprived of the vaporous envelopes which appear to obscure the surfaces of Venus, Mars, and Jupiter, it reveals even in the smallest telescopes numerous sharp and persistent details. No

[1] Translated from Annuaire du Bureau des Longitudes, Paris, 1898.

planet, therefore, seems capable of giving us greater information in regard to the question whether the physical forces (the effect of which we observe on our globe) act similarly on other celestial bodies. It lends itself, perhaps, better than the earth, on account of exposing to view a whole hemisphere at once, to the study of certain captivating and difficult problems, those for instance concerning the origin and the evolution of satellites in general. Indeed, one can not examine the moon without being led to ask if conditions favorable to the development of vegetation and of life can be found on other celestial bodies beside the earth, a question too often agitated, although always attracting philosophical interest.

The first serious attempts made to attack this problem date to the invention of the telescope. But, although skillful observers have devoted themselves to a study of the moon, it is remarkable that until recently no powerful telescope had ever been applied to a study of our satellite as a whole. Under these conditions the multitude of visible details is so great that an isolated investigator can not undertake to describe or to delineate them. On the other hand, if the task be divided among a number of astronomers, or if the attention be fixed on some particular region, there is the risk in either case of losing the character of unity of the undertaking, and in addition the physiological or accidental errors of observation would impart a provoking uncertainty to any conclusions which might be thus deduced.

II.—ADVANTAGES OFFERED IN THIS RESPECT BY PHOTOGRAPHY.

The invention of photography opened an avenue of escape from these difficulties. However, many years have been necessary for astronomers to put to application all the advantages offered to them by the new process. Their first attempts indeed met with three principal difficulties which, for a long time, were regarded as insurmountable or at least as certainly placing photography at a disadvantage with respect to visual observation.

The first difficulty was due to the imperfect achromatism of the objectives, until recently always designed for direct vision so as to bring to the same focus the brightest rays of a star without taking into account the rays which have the greatest chemical activity.

The second difficulty was due to the lack of a suitable control mechanism which would assure a persistent agreement between the displacement of the telescope and the apparent movement of the focal image of the object.

Finally, the lack of sensitiveness of photographic plates made it necessary to have recourse to relatively long exposures, which increased all the displacement due both to a defective motion of the telescope and to atmospheric undulations.

The first difficulty was overcome by MM. Paul and Prosper Henry, who demonstrated the possibility of increasing the photographic efficiency of large objectives by causing those rays which have the strongest reducing action on the silver salts to be brought to a common focus. By means of this improvement, photography, compared with direct vision, found itself in possession of an advantage which might have been theoretically predicted.

For a given diameter of the objective, the chemical rays emitted by a star will naturally produce an image richer in detail than that produced by the visible rays capable of affecting the retina. As is well known, the image of a luminous point is a small circular spot, the diameter of which is proportional to the wave length emitted. Actinic rays, more refrangible than the visible rays of the spectrum, correspond to a shorter wave length, and consequently give rise to a sharper and more detailed image if these rays are made to converge by a suitable choice of lenses.

The second difficulty has been eliminated, at least in ordinary cases, by the employment of an auxiliary telescope mounted coaxially with the photographic telescope. It therefore becomes easy to observe a star directly during the whole duration of the exposure, and to maintain the image precisely at the intersection of two fine cross hairs, by adjusting, as often as may be necessary, the mechanism controlling the motion of the telescope. In this manner the relative immobility of the stars with respect to the plates may be assured. This method can, however, only give its best results in the hands of a watchful and skillful observer. It enables, by means of prolonged exposures, sharp images of the smaller stars, suitable for the most precise measurements, to be obtained. This advance, which is also due to MM. Paul and Prosper Henry, has rendered possible the great international undertaking of mapping the heavens.

The method we possess of prolonging the exposure, almost without limit, has in certain cases a great advantage. It gives rise to an indefinite accumulation, so to speak, of luminous impressions at a given point on the plate, and thus reveals perceptible *images* of objects too dim to affect the retina. By this means vast regions of nebulous matter and numerous small planets have been discovered which no eye-piece, associated with the same objective, could have been able to reveal.

An amelioration of this difficulty has also been obtained in another manner, for chemists have succeeded in increasing the sensitiveness of photographic plates, especially by the substitution of gelatine for collodium as a body for the silver salts. In certain cases the duration of exposure has been reduced to a few hundredths or even thousandths of a second, and thus photographs of objects in motion, too rapid to be analyzed by the eye, have been obtained. In astronomy we may cite, as examples, the photography of sun spots and of granulations of the photosphere, as well as meteoric trajectories. For such a brief exposure only an approximate coincidence between the movement of the telescope and the apparent displacement of the star is necessary, and, moreover, atmospheric undulations also cease to exert an injurious influence on the image formed.

III.—CHARACTERISTIC DIFFICULTIES IN THE REGISTRATION OF LUNAR IMAGES.

All these advances have led to a kind of revolution in the methods of observation. They have also led us to undertake the solution of a great number of new problems in sidereal and physical astronomy, but none of the methods we have been discussing give entirely satisfactory results when applied to the moon. The employment of a finder makes it possible to obtain regular disks for stellar images if the stars are not too close to one another, but it does not eliminate the confusion of adjacent details in an extended object which we seek to reproduce with every possible refinement. It is necessary to adopt special mechanical contrivances to follow the moon's motion, constantly variable both in direction and in velocity. Various solutions to establish this concordance have been proposed, and, on the whole, with success. At Paris this has been accomplished in a very satisfactory manner by making the telescope immovable. The plate holder being moved by a separate motor, its orientation is therefore entirely under the control of the observer. However, as the moon is not sufficiently luminous to produce a suitable image in a small fraction of a second, it has been impossible up to the present to eliminate the effects due to the undulations of atmospheric origin. These are almost completely beyond the control of astronomy, and it is therefore necessary to select moments when they make themselves least felt. Very often they render the theoretical superiority of large objectives illusory. To show how harmful their influence is, it is sufficient to say that at Paris after four years, during which every opportunity which has appeared to be favorable for photographing the moon has been utilized, only a dozen evenings, at most, have given really satisfactory negatives which would stand strong magnification.

IV.—ADVANTAGES OF PHOTOGRAPHY OVER DIRECT OBSERVATION.

It seems that in this respect direct observation must claim a distinct advantage over photography. A very short time, indeed only a few hundredths of a second, are necessary to affect the retina.

The observer, with his eye at the ocular, can thus, if he is watching the object which he wishes to examine, take advantage of the rare intervals of calmness which are lost in photography. The nights suitable for observing will then, in the former case, be much more numerous. Notwithstanding this, however, there still remains a great superiority for photography, for a single negative obtained under favorable conditions includes an abundance of data and exact details which it would be impossible for the most patient and skillful observer

THE MOON; AGE, 4 DAYS. 6.4 HOURS.

From photograph taken at Observatory of Paris.

THE HELIOTYPE PRINTING CO., BOSTON.

to collect during a number of years; moreover, the quantity of data is of less value than their certainty. Delineations and descriptions of difficultly visible objects are in a certain measure necessarily a product of interpretation and memory. Their agreement is even very frequently not a guarantee of the fidelity of the observer, often influenced by preconceived opinions. The conditions in photography are entirely different. Instead of being temporary, as is the case with the retinal image, the chemical impression is permanent and can be rendered indestructible. A certain control can be assured by making, as is nearly always done, a number of exposures which no personal prejudice can alter. They escape all physiological and mental influences which might make the hand or the judgment of the artist deviate from the truth.

Another cause which aggravates the difficulties of direct vision is due to the presence of a complex tableau which is being continually transformed. The sensitive plate furnishes a faithful image corresponding to a given epoch.

Lack of time prevents the portrayer not from perceiving the details, but from reproducing all of them, and the subject even experiences important modifications before the work of delineating is completed. Delicate markings might be altered by the inevitable impurities of the sensitive films, of the developing baths, or of the wash water, but such alterations are easily recognized, at least as long as they do not affect details bordering on the limit of visibility. In any case, however, errors which might be introduced can easily be eliminated by making a number of exposures at short intervals apart.

It can therefore be truly affirmed that photography, having become an indispensable auxiliary for stellar astronomy, can also render important services in the physical study of the surfaces of our planets. The moon, much nearer to us than any other celestial body, would, reasoning in this manner, be a most fertile field for discoveries. During the last few years the most powerful telescopes of the Lick Observatory, in California, and of the Paris Observatory have been utilized in its study. The collections of negatives of the two observatories, taken together, inclose the elements of a complete atlas of our satellite (at present in course of publication). Not only do they reveal a multitude of details outside of those which are enumerated and represented on lunar maps, but they also furnish a certain basis for the recognition and analysis of the variations which may be wrought by time on the surface of our satellite.

V.—SOME OF THE PRINCIPAL CHANGES WHICH HAVE SUPPOSEDLY BEEN OBSERVED ON OUR SATELLITE.

The importance of a verification of such changes is extreme, and selenographers appear to have early recognized this. Fearing naturally to get lost in the infinite multitude of details, they have devoted themselves to the study of those concerning the existence of which there can be no doubt. Their efforts have been directed to obtain exact images of them and to compare their present state with previous descriptions. In the absence of precise ideas in regard to the physical constitution of the moon, they flattered themselves to have encountered traces of an evolution as active as that of which our globe is the seat; of having seen manifestations of the circulation of water, of vegetation, and of life. This hope appeared at first justified by the results. Discrepancies, which were revealed in large numbers, were interpreted as indications of probable changes. We shall briefly point out those which appear most worthy of attention.

At the bottom of the gulf, situated between the Caucasus and the Lunar Alps, we find Cassini, a crater 60 kilometers in diameter, whose ramparts rise 1,000 meters above the surrounding plain and above the interior floor. This formation, which the smallest telescope at the present day clearly reveals, is wanting on the maps of Hevelius and of Riccioli, who have represented many other objects in its neighborhood much less visible. It was first mapped in 1680 by Dominique Cassini, the author justly celebrated for the discovery of the laws of libration.

At the present day we see in the southern part of the "Sea of Rains,"[1] two twin craters very close together nearly equal in every respect, having a diameter of 20 kilometers and a depth of more than 1,000 meters. These two have been named Helicon and Leverrier. Hevelius and Riccioli again agree in mapping at this point only a single circle.

Cichus, a crater of a considerable circumference, forming part of the southern border of the "Sea of Clouds,"[2] has a paracitic crater which interrupts the regularity of its contour. On three different maps of Schröter, made between 1784 and 1802, this object is represented relatively one-half as large as it now appears.

In the same region all modern photographs show in the neighborhood of the crater "Hell" a very bright spot, in which are assembled several craters. Cassini assures us that he observed this region covered by a temporary white cloud, which disappeared to give rise to a new formation.

We actually see in the dark part of the "Sea of Clouds" a round bright spot called Alpetragius d., about 20 kilometers in diameter, without any appreciable relief. Mädler represents at this point a crater 8 kilometers in diameter, of which not the least trace can at present be found.

In the middle of the "Sea of Fertility"[3] there arise a pair of craters named after Messier. They attract attention by the straight white bifurcated trail which extends from them in an easterly direction, and resembles in a most remarkable manner the tail of a comet. These two circles, so close together, appeared exactly similiar to Beer and Mädler. Their attention having been attracted to this point by a remark of Schröter, they submitted them to a continuous examination

[1] Mare Imbrium. [2] Mare Nubium. [3] Mare Fœcunditatis.

between 1828 and 1837 without being able to distinguish the two formations from one another except by their coordinates. To-day they differ from one another both in form and in dimensions, and their dissimilarity, unanimously recognized, is so pronounced as to strike even the least attentive observer.[1]

The phenomenon described above, in the case of Alpetragius d., is repeated in the case of Linné, a white spot situated in the "Sea of Serenity."[2] Riccioli, Lohrmann, Mädler, and Schmidt all agree in representing in this place a very deep crater, from 6 to 10 kilometers in diameter and quite visible. Schmidt himself, in 1866, pointed out the disappearance of this crater. Since this epoch the spot of Linné only shows an extremely small opening, bearing no resemblance to the old descriptions.

It would be easy to extend this list by citing numerous examples taken principally from Scröter and Gruithuisen. We have only described those cases which are based on independent and concordant testimony. Indeed, in such matters the sources of error are very numerous, and the selenographers of former days do not appear to have sufficiently guarded against them. The sun, moon, and earth are only found in the same relative positions at rare intervals. A change of a few degrees in the position of the circle of illumination, or in the declination of the earth relative to the lunar equator, modifies in a marked degree the aspect of the formations which are adjacent either to the terminator or to the center of illumination. The part due to these influences being known, it remains well established by photographs, which are to-day in our possession, that the old drawings are no longer true. Do the differences correspond to effects really observed? It seems almost certain that there is no escape from this conclusion in the case of Messier, and very probably in that of Linné. In the latter case, however, there is some room for doubt, for although several drawings indicate changes, there are others which might be cited which contradict them, and hence make them open to suspicion. To show how uncertain conclusions thus established may be, it would be easy to find drawings of Mars made on the same day and at the same hour by two different observers in which even the most important markings could

[1] Since this verification is the most precise we possess, we will quote from the writings of Beer and Mädler, whose authority in selenography is so great and so well founded: "To the east there arises a crater similar to the first in all respects in form, height, depth, color of the interior and of the rampart, and even in the position of certain summits on the latter. The entire agreement is so pronounced, that it must have been due to a singular stroke of chance, unless some unknown law of nature has thus manifested itself. We are certain that since 1829 we have seen this region, as we have just described it on more than three hundred occasions; in other words, as often as it could be observed. In a formation so well characterized the least changes of size, shape, or luminosity would have made themselves visible, the observations of Schröter having induced us to keep a sharp watch on this locality."

[2] Mare Serenitatis.

not be identified. If two such drawings were considered as relating to different epochs, there would have been a great temptation to assume that there had been a profound transformation, while everything is explained by errors of interpretation of a physiological origin, which arise when the attention is concentrated for a long time on objects which are scarcely visible. The situation would be entirely different for the moon if we had negatives taken fifty or sixty years ago comparable in quality with those obtained at the present time. Under these circumstances there would be no uncertainty as to surface changes of any moment.

VI.—INDICATIONS FURNISHED BY RECENT PHOTOGRAPHS IN REGARD TO THE ORIGIN OF THE LUNAR CORE.

Let us now examine what profit science can hope to reap from the study of photographs taken in the last few years. They confirm, on the whole, the correctness of the work of Mädler and Schmidt, and show that no phenomenon which has modified in any permanent manner the general aspect of the moon has taken place in the last half century. Concerning local variations, it would be wise not to draw any absolute conclusions and to consider the recent photographs as beacons erected for the future. The value of lunar photographs can not fail to increase with time, and they will doubtless permit us to draw definite conclusions within a few years which the sketches of two centuries ago would not authorize. Moreover, the photographs are even to furnish us at once with other very important data from another point of view, for giving, as they do, a homogeneous and simultaneous representation of the whole visible disc, they lend themselves very well indeed to a study of the origin of the lunar soil. They possess particular advantages in the recognition of the general alignments in the structure of the soil, the delicate tracings which extend for great distances, such as the so-called cracks and radiating streaks.

These objects are most difficult to distinguish by direct observations, the attention of the astronomer being in this case strongly concentrated on a restricted portion of the image. Another valuable property of photography is that it brings out in an expressive manner, possibly slightly exaggerated, the differences in the tint of two neighboring regions. Such indications have a great value in the study of the actual physical state of the moon, and, notably, in proving the presence or absence of air and water on its surface. We are now to take up a consideration of this question, which is intimately connected with the problem so often suggested of the habitability of the planets.

VII.—ON THE EXISTENCE OF WATER AND AIR ON THE MOON.

The complete absence of air and of water on the moon would be considered at first sight as an abnormal condition. It is indeed difficult, whatever cosmic theory one adopts, not to regard the moon as a depend-

THE MOON; AGE, 7 DAYS, 21 HOURS.

From photograph taken at Observatory of Paris.

ency or a colony of the earth. To be more precise, and considering the question from the standpoint of Laplace, the satellites ought to be considered as fragments of the planet they accompany, these fragments having been derived from its equatorial and superficial layers. The materials which predominate in the original body ought to be represented in the satellite, and especially the fluids and other light substances which gravity tends ceaselessly to conduct to the surface. This supposition is confirmed by the low mean density of the moon, hardly greater than one-half of that of the earth. It might generally be supposed that the division of the original atmosphere would have taken place in proportion to the masses of the two bodies, and one ought not to expect to find the air on the surface of our satellite forming a layer as dense as that on the terrestrial globe. The ratio of the surface to the volume of the moon is four times as great as that of the earth, and gravity, reduced to a sixth part of its value, would more or less efficiently counterbalance the expansive force of gases and vapors. The lunar atmosphere would therefore be expected to extend to a much greater height than ours, producing a corresponding decrease in its density. For these two reasons it may be predicted that the air at the surface of the moon can not possess a refracting power as great as one-fiftieth of that on the earth's surface. Observation, however, shows that it must be very much less than even this.

VIII.—INDICATIONS THUS FAR OBTAINED BY DIRECT OBSERVATIONS.

If our satellite possessed a layer of air of appreciable density its presence would surely be revealed in several different ways: (1) The diameter of the moon would be increased, its apparent contour being no longer determined by straight tangents drawn from the observer to the lunar globe, but by rays which are tangent to its surface, after having been curved in its atmosphere. Assuming that refraction is still sensible at a height of five kilometers above the lunar surface, this would result in an increase of about five seconds in its apparent diameter, and in a band of about two seconds width, there would be a superposition of images, which would detract very much from the sharpness of the moon's outline. Bright stars would, before disappearing, seem for a few seconds to travel on the lunar disk. (2) The apparent diameter, calculated from the duration of the occultation of stars, would, on the contrary, be smaller than the apparent diameter defined by geometric tangents. A phenomenon similar to that observed at the rising and setting of the stars would result. Refraction transforms the luminous rays into curvilinear trajectories, with their concavity always turned toward the center of the earth. Therefore, for example, the time of sunset is retarded and that of sunrise is hastened by the same amount. In the case of an occultation the effect would be twice as great seen from the earth as it would be for an observer on the moon at the point of tangency of the luminous ray emitted by the star. The ray, to reach us, would, in fact, have to traverse the lunar atmosphere twice, being twice deflected, but always in the same direction. To be concise, the duration of an occultation would be shortened and the diameter of the disk, calculated from the time of entry and exit, would be less than the true diameter, and, a fortiori, less than the diameter given by micrometric measurements or by transit observations. In the case of an oblique passage of a star behind the disk the trajectory of the star would be sensibly inflected. (3) On days preceding or following new moon the narrow horns, which terminate the illuminated portion, ought to be prolonged beyond their geometric limits—a twilight effect. (4) In an eclipse of the sun that portion of the lunar disk not projected on the sun's surface should appear, partly, at least, surrounded by an aureole similar to that which has often been observed during the transits of Venus. The light from the solar corona would be reinforced in these parts, the refracted rays adding their effects to those which are directly transmitted. (5) The spectral rays of atmospheric origin, compared with those of solar origin, should be relatively more pronounced in the light reflected by the moon than in that received directly by the sun. (6) Finally, if one assumes that the atmosphere of the moon contains a considerable quantity of water vapor, as does our own, it would appear improbable that this vapor, submitted to extreme temperature changes due to days and nights fifteen times as long as our own, would not condense to form clouds or deposits of snow readily visible.

Most of these indications have repeatedly been observed, according to the statements of astronomers worthy of belief. They can, however, hardly be considered as established by sufficiently precise and concordant testimony, depending, as they do, on such data as the prolongation of the horns by night and the theoretical duration of occultations. To cite one more fact, the only one on which a numerical evaluation can be based, and which has only been brought to light quite recently; it is to-day admitted that the semidiameter of the moon, deduced from meridian observations should be diminished two to two and a half seconds, to conform to observations of occultations and eclipses. At the beginning of this century, on account of the lack of sufficiently numerous and exact measurements, the two values of the diameter were regarded as identical. Based on this assumption, the illustrious Bessel was of the opinion that he could affirm that the atmospheric density at the surface of the moon could not be greater than $\frac{1}{900}$ of its value on the surface of the earth. If the same calculation be repeated on the basis of the recent discussion of accumulated observational data, it would lead to the assumption that the moon does possess an atmosphere and that its density is slightly greater than that assigned by Bessel as a maximum limit.

It would be wrong, however, to accept this conclusion as absolute. We do not know the diameter of the moon, as determined by direct measurements, with sufficient exactness, and consequently we are not able to affirm that the discordance pointed out may not be due to other physical causes. However, it remains established that the principal reason usually given for denying the existence of an appreciable atmosphere around the moon has actually no value, and the probabilities should rather be considered as in favor of its existence.

From this ensemble of facts the conclusions may be drawn that the density of the atmosphere on our satellite is certainly very much less than it ought to be, if its division between the moon and the earth had originally taken place in proportion to their masses. This result might, moreover, have been foreseen by theory. Indeed, during the separation of the earth and moon there must have been a considerable time during which the two planets were enveloped in a common atmosphere. The action of masses at a distance being governed by the law of universal attraction, it would necessarily follow that the atmosphere would be divided, not in the ratio of 1 to 8, which is that of the two masses, but in the ratio of 1 to 729, which is that of the volumes of the attracting spheres.

This remark permits us to consider the small relative density of the lunar atmosphere, verified by observation, as being perfectly in harmony with Laplace's hypothesis.

Should one conclude from the above that our satellite has always possessed only an extremely rare atmosphere, incapable of sustaining life, and of being the seat of meteorological phenomena of importance? By no means. It may be supposed that at the epoch when the division of the atmospheres of the two globes was accomplished, that of the earth was incomparably more extended than to-day. An elevation of the the temperature of a few hundred degrees would transform the water of the ocean into water vapor and would also set free all the carbonic acid locked up in limestone formations. The small portion of the common atmosphere with which our satellite was endowed ought, then, on this principle, to have had a density much greater than its present value.

The examination of recent photographs furnishes us with numerous and decisive data even on this important question, enabling us to affirm with certainty that the lunar atmosphere was at some previous time much more dense. This conclusion is almost forced upon us by intense and manifold volcanic phenomena, of which we discover undeniable traces in nearly every region of the moon.

Even if the inferior density of the materials displaced be considered, explosions and upheavals could not have been produced on such a large scale without having been accompanied by an abundant disengagement of gases. It must be evident, from our knowledge of active volcanoes, that no agent could have supplanted water vapor in this function. The scattering of eruptive products to great distances in the form of radiating streaks which clear all obstacles can not be comprehended except on the assumption that they were emitted in a powdered state and held in suspension in an atmosphere sufficiently dense to temporarily support them.

IX.—CAUSES WHICH MAY HAVE LED TO THE DISAPPEARANCE OF THE WATER AND THE ATMOSPHERE.

The preceding conclusions, taken together, lead to the result that the moon is incapable of preserving in a gaseous state the substances distributed over its surface. Its feeble gravitational attraction would permit the lighter gases, such as hydrogen, etc., to escape if they be raised to a high temperature or be endowed with sufficient kinetic energy. The denser gases, having entered into stable combinations, would have become incorporated with the core. The liquid portions would have disappeared by means of mechanical absorption. The continuity and the efficiency of this tendency are manifested by the phenomena which are daily taking place about us.

Thus the continually increasing predominance of solid compounds in a gradually cooling body would result in accordance with the most general laws of chemistry. Most saline compounds contain water of combination which they set free on being heated and which they take up again on cooling in a moist atmosphere. This phenomenon would be limited, both by the complete saturation of the salts and by the total disappearance of free water vapor. These two conditions can be experimentally realized in laboratories. The first is that generally presented on the surface of the earth, but the second would be found on a planet less well provided with water.

It is even probable that the evolution of the earth on which we dwell will not cease to continue in the same direction. The incessant cycle of changes which water undergoes under our very eyes, and which seems a necessary condition for vegetation and life, is not fixed and will not endure forever. The formation of deposits of rock salt, gypsum, and nitrates effectively abstracts a very considerable quantity of water from circulation. The water uniting with the solid salts can then no longer be separated from them by the ordinary operation of natural forces. What we have said above in regard to the water applies equally well to the other components of the atmosphere. From it have been abstracted the carbon contained in limestone formations and in coal beds, the nitrogen in vegetable soils and in the Peruvian nitrate beds, and finally the oxygen of siliceous rocks. Nothing indicates that this transformation has already been completed, and that it will not be continuously manifested by the lowering of the ocean level and of the barometric column.

There is, moreover, a special cause operating to abstract water from circulation apart from chemical action. The major part of the terrestrial core is formed, as is well known, of permeable rocks. The water carried down by rain filters through them, saturating them more or less completely, according to the season, filling the cavities which there abound or circulating in capillary fissures, compressing and expelling any gases which are encountered. The same phenomenon must also be going on at the sea bottom, and in addition gravity always tends to remove the water farther away from the surface. The absorption is, however, limited by the internal heat of the globe. At a depth of 3,000 or 4,000 meters the water would be brought in contact with layers at a temperature of 100°. It would therefore be vaporized and the tension of the vapor formed would be sufficient to partly drive back the water into the upper layers or even to spurt it out in the form of thermal springs. This subterranean circulation of the water is probably the most active cause of the loss of the internal heat of the globe. In proportion as the cooling progresses the depth of the layer, in which water can exist in the liquid state, would increase and its capacity for absorption would thus be still further augmented.

If we give due weight to the difference in the physical conditions on the earth and on the moon we become, without difficulty, convinced that all the causes which have tended to diminish the height of the atmosphere and the volume of the ocean on our globe must have had a still greater influence on our satellite. Less well provided with air and water originally, and with a greater extent of surface in proportion to its volume, the moon would take less time to consume the reserve supplies. The formation of saline compounds, of limestone, gypsum, and nitrates must have been able to effect a nearly complete absorption of the water before even the cooling would have permitted its condensation on the surface. The remainder, having escaped these causes of absorption or having been again set at liberty by volcanic eruptions, must have filtered into the innumerable orifices of every size which honeycomb the lunar core. In addition, the penetration would be more easily effected than on the earth, for the internal temperature, decreasing more rapidly with the depth, would not tend to prevent that action to the same extent. To briefly summarize the above it must be considered as established by observation that the moon does not at present contain either bodies of water having a free surface or an appreciable atmosphere. If it be demonstrated, however, that water in the form of vapor has actively contributed to the formation of the present relief, we can not tell a priori whether water has ever circulated in the liquid form at some intermediate period or whether it had time to be condensed on the surface before being absorbed, before accomplishing important mechanical effects, or before finally giving rise to the formation of great accumulations of ice.

On these different points there is abundant opportunity for interrogating unprejudiced observation, and for examining if our satellite shows any evidences of eroded valleys, sedimentary deposits, and ice fields of considerable extent—phenomena which ought to result from the prolonged action of water. Modern photographs will throw much valuable light on this subject.

Although it is easy indeed to find on the surface of the moon regions similar in their aspects both to the low plains and the elevated plateaus of the earth, the differences become accentuated on comparing the mountainous regions, properly so called; that is to say, those in which differences in level of several thousand meters appear short distances apart. Wherever this condition is encountered on our globe it may be observed that the relief of the surface has been totally transformed by the action of water, and the inspection of sedimentary deposits shows that our present mountain chains are but a small residue of the primitive formations. Formations rising boldly above the general level have undergone a progressive erosion, especially their contour, and the direction of their greatest elongation is to-day marked by a crest or a divide the more marked the higher the mountains.

The causes which lead to the appearance of these divides also give rise to the formation of secondary ridges. Between these ridges the valleys appear, which deepen and enlarge gradually from their source to their junction with the plains below. Some of them, deepened by numerous rivers, conduct to a common destination all the waters of a vast region, and not infrequently acquire important dimensions. There is often a distance of 10 to 15 kilometers between the ridges on either side. Vast basins would also be easily recognized under an oblique illumination on the present scale of lunar photographs, and we would be able to verify without any difficulty their general character of convergence.

The evidences which we to-day possess cause the lunar mountains to appear in an entirely different aspect. Rarely is a sharply defined watershed found, and even in this case it is easily recognized that it is the edge of a plateau of which only one side shows a marked declivity extending for a considerable distance and marked differences in level. From this standpoint, at least, we should have conditions most favorable for indicating the action of flowing water. We find, however, that there are no large basins formed such as abound among the high mountains of our globe. The depressions there encountered are isolated and closed from all sides. They show no progressive extensions, no tendency to ramify toward the ridges or to converge in descending toward the plains.

These facts taken together appear to us irreconcilable with the idea that there was ever an important circulation of water on the moon. It is hardly necessary to point out that if there were any bodies of water at present they would be revealed by their aspects and by their power of reflecting solar light.

X.—THE PRESENCE OF ICE ON THE SURFACE OF THE MOON.

It might be thought that if water has not accomplished any important mechanical changes on our satellite this might be due to the rapid cooling of the lunar globe, the water having thus passed in a short space of time from the gaseous to the solid state. It may be assumed from this standpoint that the moon is enveloped, even at present, by an uninterrupted coating of ice. This view has been adopted by various skillful observers, especially by Raynard. It is my opinion that it can no longer be defended to-day, and that the modern photographs do not permit us to assume the presence of any considerable quantity of ice upon the surface of the moon.

The hypothesis of an ice coating appears seducing on account of the fact that a general cooling appears to progress more rapidly than the absorption of the water, at least on the earth's surface. Accordingly it may be predicted that at some future time the greater part of the ocean will have been transformed into the solid condition. The moon, therefore, would offer us an image of the future state of our globe.

It is also true that the measurements of radiant heat made by various physicists, especially by Langley, have led to the view that, on the whole, the lunar disk is at a very low temperature even when in opposition.

On the other hand, if the lunar disk were covered with ice one ought to see a luminous spot periodically appear following the motion of the sun. Ice, indeed, possesses a marked power of reflecting light, although to a smaller degree than water. Neither photography nor visual observation indicate anything of this kind, besides the measurements of M. Landerer give a value for the angle of polarization of the surface of the moon differing from that of ice and agreeing much better with that of volcanic rocks.

It seems also very improbable that a bed of ice spread over the equatorial zones could undergo for two consecutive weeks the direct action of the solar rays, to be for several times twenty-four hours beneath the sun near its zenith, without being heated to the melting point and consequently giving rise to the production of bodies of water and of clouds. Although the high summits of terrestrial mountains remain cold in the summer and although the snows which cover them melt but slightly, this may be attributed to the violent winds which there abound and which prevent the temperature of the surface from exceeding that of the air. But the melting of the snow does take place under the sun's exposure in localities sheltered from the wind. On the moon, however, the air is too rare to remove by convection any considerable quantity of heat from bodies, and hence the action of the sun is exercised in an extremely energetic and prolonged manner. The supposition that the glacial coat of the moon is covered by another, formed of scoriæ and cinders, is in better agreement with its superficial aspect, but the resistance past and present offered by the ice to fusion must still be regarded as most mysterious. The scoriæ indeed should have an elevated temperature, for they heat up under the action of the sun even more readily than ice. Water surfaces should therefore appear periodically at least in the bottoms of great depressions.

The hypothesis that the entire surface of the moon is covered with ice appears to us inadmissible. It is natural to inquire whether its accumulation might not take place exclusively in the neighborhood of the poles as in the case of the earth and probably that of Mars. No doubt these regions nearly deprived of the action of solar heat ought to cool down first.

The vapors formed in the low latitudes would condense at the poles in the form of snow, and would thus be withdrawn from circulation, since the temperature at the poles must have become too low to melt or vaporize it. Starting from the moment this temperature is reached, the ice would not cease to accumulate at the poles until the equatorial zone itself had permanently cooled to the freezing point. Moreover, since this general cooling could only have been accomplished extremely slowly, the poles would have time to accumulate a great quantity of ice. Their aspect would consequently be more united than that of the equatorial regions on account of the effacement of the smaller depressions. The lunar photographs, however, reveal just the contrary. The southern region of the moon is particularly mountainous, bristling with irregular formations. The craters are very numerous in this locality, many touching the limit of visibility, and there are, without doubt, many more which escape our means of observation. On the hypothesis of two polar ice caps it seems impossible for the intermediate zones not to be distinguished by too easily distinguished lines of demarcation undergoing periodic oscillations. Indeed, no known rock taken as a whole possesses a power equal to that of snow or of ice for reflecting and diffusing light. The distinction could perhaps be made without difficulty on terrestrial mountains 200 kilometers off, through the lowest and most highly refracting layers of the atmosphere, conditions under which these mountains would appear infinitely less sharply defined than the craters of the moon. It seems that all we can reasonably admit is the possible existence of deposits of ice on the floor of the craters in the polar regions. There they would be nearly removed from our sight and sheltered from the radiation of the sun. Reduced to these terms the question can only be answered by an absolute negative. It may be pointed out, however, that the bottoms of the craters appear relatively white in the neighborhood of the poles but never more so than the neighboring crests and plateaus. There can exist, therefore, only glacial masses of slight thickness and of small extent, probably covered with cinders. Notwithstanding this, it is to be hoped that the changes which should accompany their temporary liquefaction ought to be revealed some day by the careful comparison of photographs.

XI.—CONCLUSIONS.

The result of this inquiry, as may be seen, is unfavorable to the actual existence of water, air, and ice in any considerable quantity on the moon. The climatic conditions must therefore be very severe, not only in the polar regions, hardly touched by the grazing rays of the sun, but even in the equatorial regions. Deprived of the protecting mantle formed by the air and the water vapor, it is subjected to the same conditions, in a more aggravated form, as the highest terrestrial mountains, the most extreme dryness, intense nocturnal radiation, and a very low mean temperature. One can hardly imagine an abode more unfavorable for the existence of human life, and as even the most rudimentary forms are absent on the earth at great altitudes, it is impossible to conceive of any which could adapt themselves to the moon in its present state.

The same conclusion seems valid, however deeply the question be considered.

Without doubt the elements of our terrestrial atmosphere have existed on our satellite. Water in the form of vapor has exerted a most energetic action, and has formed a relief more marked, on the whole, than that of the earth. The atmosphere must, however, have been quite rare when the surface temperature reached the condensation point, and must have been almost entirely absent when it reached the freezing point. The conditions of humidity and temperature required for the development of terrestrial organisms are therefore never found together on the moon. Its history has many features in common with the primitive evolution of the earth, though none, it appears, in common with the contemporaneous period. The moon seems like a planet of which the development has been prematurely arrested, fixed in its final form, to become a mute spectator of our own agitations.

Should we for this reason forsake the study of that sterile globe as being without interest? We should regard the question from a broader standpoint. The period when life flourishes is but a chapter in the history of a celestial body, although without doubt the most interesting one, but we can not consider it only at its best without extending our researches still further. Physical and chemical laws develop their consequences within the widest limits of time, and we find in the series of transformations of a planet a subject having an almost equal philosophical importance. The photographic observation of our satellite is, from this point of view, full of promise.

Although incapable of sustaining organized life, the moon will nevertheless continue to exert a permanent action in the development of the human mind. By the study of the important phenomena which are connected with its attraction for the earth, it has given rise to the highest efforts of mathematical genius. It aids us in conceiving a more just and disinterested view of the universe as a whole. It makes us reach out in thought, not only from ourselves, but from the earth where we abide, and from the short lifetime in which all our experiences are embraced.

THE MOON: AGE, 8 DAYS, 21.5 HOURS.

From photograph taken at Observatory of Paris.

THE HELIOTYPE PRINTING CO., BOSTON.

THE FUNCTION OF LARGE TELESCOPES.[1]

By George E. Hale.

The annual exhibitions of the New York Academy of Sciences afford excellent opportunities for studying the progress of science. The photographs and specimens gathered here to-night are substantial evidence that in no department of research have investigators been idle during the last twelvemonth. So true is this, that to sketch the year's advances in even a single field would consume more time than is allotted to the annual lecture. It therefore seemed to me wise, in responding to the courteous invitation with which I was honored by the council, to select a subject involving certain details of astronomical progress, without attempting to undertake the inviting task of portraying the rapid advances which make up the recent history of the science. I accordingly invite your attention to some considerations regarding the function of great telescopes.

On the 21st of last October, in the presence of a large company of guests, the Yerkes Observatory was dedicated to scientific investigation. The exercises were held under the great dome of the observatory, beneath the 40-inch telescope. Is there reason to suppose that some in the audience, particularly those having no great familiarity with astronomical instruments, were inclined, in the course of the reflections to which the occasion may have given rise, to attribute to the great mass of steel and optical glass rising far above their heads some extraordinary and perhaps almost supernatural power of penetrating the mysteries of the universe? It is not at all unlikely that this was the case. For there apparently exists in the public mind a tendency to regard astronomical research with a feeling of awe which is not accorded to other branches of science. In its power of searching out mysterious phenomena in the infinite regions of space, a great telescope seems to stand alone among the appliances of the investigator. Partly because of this special veneration for its principal instrument, and perhaps still more on account of the boundless opportunity for speculation regarding the origin and nature of the universe, astronomy appears to command the interest of a great portion of the human race. No doubt there are also historical reasons for the special attraction which the

[1] An address given at the fifth annual reception of the New York Academy of Sciences. Printed in Science, Vol. VII, No. 176, May 13, 1898.

subject seems to exercise. In the more prosperous days of the countries bordering on the Mediterranean astrology played an important rôle, and mediæval history illustrates most clearly the ascendency which the fancies of the astrologers had acquired over even cultivated minds. So strong was the tendency of the times that even so able an astronomer as Tycho Brahe was wont to cast horoscopes, in the significance of which he firmly believed. He concluded that the new star of 1572 prognosticated great changes in the world. Similarity to the ruddy planet Mars pointed to wars, pestilence, venomous snakes, and general destruction, and its resemblance to Venus, Jupiter, and Saturn at other times foretold temporary pleasant influences, followed by death and famine.[1] Thus the heavenly bodies in their courses were supposed to exercise evil or benign influences upon the human race, and the apparition of a great comet or a new star gave rise to endless speculations regarding the fate to which the inhabitants of the earth were shortly to be exposed. Even in our own day it can not be said that we have altogether escaped from the entangling meshes of the astrological net. With that strong desire to be humbugged which Dr. Bolton has so well illustrated in his recent paper in Science on Iatro-Chemistry, a portion of the general public seems to devote itself with enthusiasm to the encouragement of charlatans, whether they deal with alchemy, with medicine, or with astrology. So it is that astrologers flourish to-day, and continue to derive profit from their philanthropic desire to reveal the future to inquiring minds.

The interest of cultivated persons in astronomy and in the possibilities of great telescopes is by no means to be compared with the blind grouping of less-developed intellects after the mysteries of astrology. But if we must regard the large circulation of certain newspapers as any index to the popularity of their contents, we are forced to admit that their readers may comprise a class of persons whose admiration for the science is at least distantly related to the love for the sensational which dominates the followers of modern seers and soothsayers. Great telescopes are no sooner erected than these papers begin to demand extraordinary revelations of celestial wonders. The astronomer, quietly pursuing his investigations in the observatory, is from time to time startled by imperative demands to introduce a waiting and anxious public to the equally expectant inhabitants of Mars. Minute particulars as to the appearance, strength, stature, and habits of these hypothetical beings, whose existence is freely taken for granted, are expected to be the results of a few moments' observation with the great telescope. When the astronomer mildly protests that his observations are likely to afford little or no material for discussions of such topics, he is at least supposed to so cultivate his imaginative powers that he shall be able to supplement his unsatisfactory observations by intuitive perception of things which are beyond his telescope's unaided

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[1] See Dreyer's Tycho Brahe, p. 50.

appreciation. And it must be admitted that this demand on the part of some portion of the public press, while in one sense only a certain phase of the almost universal desire for sensation, has not lacked encouragement from men who are generally regarded as serious astronomers, intent on arriving at the truth by the methods of exact science. To such is due a widespread belief in the inhabitants of Mars, who in the popular novels of the day have not even been content with life upon their own planet, but, in accordance with the astrological significance of the god of war, have come to bring destruction upon the inhabitants of the earth. However entertaining we may find the doings of these strange individuals, whether at home or abroad, we must not make the mistake of classing the works which describe them with the literature of science, but rather accord them their proper place among the pleasant romances which we owe to men of letters.

I can not better illustrate one phase of this pseudoscience than by a reference to the celebrated "Moon Hoax," which caused such a stir at the time of its appearance. When Sir John Herschel sailed for the Cape of Good Hope in 1833 he little imagined what marvelous discoveries lay before him. It is true that he was provided with a great reflecting telescope of 20 feet focal length, which was to be used upon the previously unexplored regions of the southern heavens, and it could not have been difficult for him to form some conception of the valuable additions he was certain to make to astronomical knowledge. But the imagination of others by far outran the more prosaic course of his own mind, and results were obtained for him which unfortunately his telescope never served to show. Many who are present are no doubt familiar with a pamphlet entitled Great Astronomical Discoveries lately made by Sir John Herschel, LL. D., F. R. S., etc., at the Cape of Good Hope, which was "first published in the New York Sun, from the supplement to the Edinburgh Journal of Science." In the truly entertaining pages of this ingenious narrative we find an example which certain reporters of our own day seem to have taken to heart. Let me quote a paragraph of nonsense which is so amusingly conceived and proved so effective when published that one is almost ready to forgive the perpetrator. After a lucid historical discourse on the great telescopes which had been made by Sir William Herschel and other previous investigators, followed by an impassioned paragraph which may well be considered to approach in eloquence the most fervid astronomical literature of our own day, our author treats us to an account of a conversational discussion between Sir John Herschel and Sir David Brewster, which began with a consideration of certain suggested improvements in reflecting telescopes, and soon directed itself "to that all-invincible enemy, the paucity of light in powerful magnifiers. After a few moments' silent thought, Sir John diffidently inquired whether it would not be possible to effect *a transfusion of artificial light through the focal object of vision!* Sir David, somewhat startled at the originality of the idea, paused a while, and then hesitatingly referred to the refrangibility of rays and the angle of incidence. Sir John, grown more confident, adduced the example of the Newtonian reflector, in which the refrangibility was corrected by the second speculum, and the angle of incidence restored by the third. 'And,' continued he, 'why can not the illuminated microscope, say the hydro-oxygen, be applied to render distinct, and, if necessary, even to magnify, the focal object?' Sir David sprung from his chair in an ecstacy of conviction, and, leaping half-way to the ceiling, exclaimed, 'Thou art the man!' Each philosopher anticipated the other in presenting the prompt illustration that if the rays of the hydro-oxygen microscope, passed through a drop of water containing the larvæ of a gnat and other objects invisible to the naked eye, rendered them not only keenly distinct, but firmly magnified to dimensions of many feet, so could the same artificial light, passed through the faintest focal object of a telescope, both distinctify (to coin a new word for an extraordinary occasion) and magnify its feeblest component members."

Here, indeed, was a discovery fit to startle the world; and one can not be surprised that, after so extraordinary an advance, Sir John Herschel should have immediately arranged for the construction of an object glass 24 feet in diameter. Contributions toward this important work were received from many royal personages, culminating in a gift by His Majesty the King of some £70,000, which was considered ample to meet all expenses. Many difficulties were encountered in casting the great object glass, which was composed of "an amalgamation of two parts of the best crown with one of flint glass, the use of which in separate lenses constituted the great achromatick discovery of Dollond." Notwithstanding the prodigious size of this enormous lens, which weighed 14,826 pounds after being polished, and whose estimated magnifying power was 42,000 times, Sir John was not satisfied. Not content with the mere illuminating power of the hydro-oxygen microscope, "he calculated largely upon the almost illimitable applicability of this instrument as a second magnifier which would supersede the use and infinitely transcend the powers of the highest magnifiers and reflecting telescopes." Indeed, so certain was he of the successful application of this idea that he counted upon "his ultimate ability to study even the entomology of the moon in case she contained insects upon her surface."

It would be interesting, if time permitted, to consider with our inspired author the various further details in the construction of a telescope which was the first to render visible the inhabitants of the moon. It may well be imagined with what breathless interest the report of Sir John's extraordinary discoveries, which constitutes the body of our pamphlet, was received by a willing public. "It was about half-past 9 o'clock on the night of the 10th, the moon having then advanced within four days of her mean libration, that the astronomer adjusted his instruments for the inspection of her eastern limb. The whole immense power of his telescope was applied, and to its focal image about one-half of the power of his microscope. On removing the screen of the latter, the field of view was covered throughout its entire area with a beautiful, distinct, and even vivid representation of basaltic rock." For further details regarding the rock and the lunar flora which covered it, reference must be made to the original pamphlet. There, too, can be found descriptions of deep blue oceans, breaking in large billows upon beaches of brilliant white sand, girt with wild castellated rocks. Passing inland, wide tracts of country of apparently volcanic character were rapidly passed over, soon bringing to the observer's eye lofty chains of slender pyramids of faint lilac hue, which, when examined with the highest power of the instrument, were seen to be monstrous amethysts reaching to the height of 60 to 90 feet, and glowing in the intense light of the sun. It must not be supposed that such delightful regions were devoid of life. Birds and beasts of strange and uncouth form were soon brought to view, and, last and greatest marvel of all, the observer was permitted to behold beings of manlike form. Although not seen engaged in any work of industry or art, they were evidently of a high order of intelligence, and to them was doubtless due a magnificent temple, built of polished sapphire, with roof of yellow gold. The observer did not at the moment pause to search out the mystery symbolized in the unique architectural details, for he was then "more desirous of collecting the greatest possible number of new facts than of indulging in speculative theories, however seductive to the imagination."

But we have already dwelt too long upon this product of enterprising journalism, which poor Sir John was too far away to be able to contradict. It is enough to remark that the author accomplished his immediate purpose, and moreover bequeathed to future generations a classic in this special field of literature.

The astronomer of to-day is unfortunately exposed to similar misrepresentation. On account of the fact that it is a little larger than any other refractor, the Yerkes telescope is particularly open to attack. Take, for example, these sentences from a newspaper which would not ordinarily be considered as one of the sensational class: "After Professor Barnard had swept the sky in the region of the nebulæ he pointed the instrument toward a region located to the astronomer in Pos. 312 degrees; Dist. 53 minutes. He swung the giant tube toward the region, and the first discovery at the Yerkes Observatory was registered on the dial near the dome." This is merely the newspaper's own peculiar way of paraphrasing a simple statement in the Astrophysical Journal regarding the detection of a faint star near Vega. A persistent search by all the members of the staff has not yet brought to light the mysterious "dial near the dome," with its precious record of discovery. It seems probable that the same dial must have treasured up the remarkable observations of the moon, which the Associated Press thought worthy of transmission to Europe, though they originated in a reporter's fertile brain, and still remain unknown to the telescope to which they were ascribed. An influential newspaper selected these latter observations as the text of an editorial setting forth the marvelous benefits the Yerkes telescope is destined to confer upon mankind.

It may be added that the great telescope of the "moon hoax" is hardly more extravagant in conception than certain schemes which have been proposed in all seriousness within the past year. One of these inventors, whose familiarity with the difficulties of telescopic observation is certainly surpassed by his optimism, remarks: "I think the limit (of magnification) will be due to the shaking of the instrument caused by the trembling of the earth and of the clockwork mechanism which moves the telescope. Under these high magnifications extremely minute vibrations are so much magnified that a small object like that of a house upon the surface of Mars would dart in and out of the field of vision so as to prevent its being photographed." And this he believes to be the only obstacle (though fortunately it is to be overcome) which can interfere with his studies of Martian architecture.

So far we have considered only what great telescopes can not accomplish, and were I not to pass rapidly on to some positive statements of another character I might be supposed to believe that they have no reason for existence, or at best are no better than small ones. But I shall endeavor to show that exactly the contrary is true; that while large telescopes do not possess the extraordinary powers conferred upon them by fertile imaginations, they nevertheless play a most important part in scientific research, and render possible many investigations which are altogether beyond the reach of smaller instruments. It seems the more necessary to dwell upon this point, for only a few years ago there appeared in print an article entitled "Do large telescopes pay?" which was evidently not written by one of those to whom reference has just been made, but by one of another class, whose known acquaintance with astronomical work would tend to give his opinion considerable weight with many intelligent readers. In discussing the subject it was seriously asked whether the great investments of money which had been made in the giant instruments of the latter half of the nineteenth century had been attended by commensurate advances in astronomical knowledge. The question is certainly one that deserves serious consideration, for it would surely be poor policy to erect great telescopes if they are no better than smaller and much cheaper ones. It is desirable, therefore, to point out, if I can, some of the elements of superiority of large instruments which seem to me to make them worth all that they cost and more.

Leaving aside reflecting telescopes, as most of the very costly instruments in use are refractors, it will be seen that our problem is, for the most part, a comparison of the proprieties of a large achromatic lens with those of a small one. To render the discussion more definite let us compare a 40-inch lens of 62 feet focus with a 10-inch lens of 15½ feet focus. The large lens, then, has a diameter four times that of the small one, which means that its area is sixteen times as great. It will thus receive upon its surface from a given star sixteen times as much light, and all of this will be concentrated in the point-like image of the star, except that portion which is lost in transmission through the lens. On account of its greater thickness the large lens transmits only about 65 per cent of the visual rays that fall on it, while the small lens transmits about 77 per cent. But after allowance has been made for the loss due to both absorption and reflection it is found that the image of a given star produced by the large telescope will be nearly fourteen times as bright as that given by the small one. In this instance all of the light is concentrated in a point, but in the case of a planet or other extended object, on account of the fact that the focal length of the telescope increases as its aperture increases, the brightness of the image is no greater with the large glass than with the small one. The image is, however, four times as large, and this has a most important bearing upon certain classes of observations, particularly in photographic and spectroscopic work.

There remains still another peculiarity of the large lens as distinguished from the small one. On account of the nature of light, the power that a lens possesses of separating two luminous points which are so close together as to be seen as a single object by the unaided eye depends directly upon its aperture. Thus, if we consider a double star the two components of which are separated by a distance of 0.5″ of arc, it will be barely possible with a 10-inch telescope to resolve the star into two points of light just touching one another. If the members of the pair are closer than this, they can not be separated with a 10-inch glass, no matter what magnifying power is used. With a 40-inch telescope, on the other hand, it is not only a simple matter to separate stars 0.5″ apart, but it is even possible to distinguish as two points of light the components of a double star of only 0.12″ separation.

To sum up, then, we see that the principal advantages of a 40-inch object glass as compared with one of 10 inches aperture are, first, its power of giving much brighter star images, and thus of rendering visible faint stars which can not be seen with the smaller telescopes; second, the fact that it gives at its focus an image of any object, other than a star, four times as large as the image given by a lens of one-fourth its aperture and focal length; and, third, its capacity of rendering visible as separate objects the components of very close double stars or minute markings upon the surface of a planet or satellite. Mention should be made here of the fact that the large glass assuredly has some disadvantages as compared with the smaller one, particularly in that it requires better atmospheric conditions to bring out its full qualities. But I think it will be seen from what follows that these disadvantages are by no means sufficient to offset the great advantages possessed by the larger instrument. Let us now consider what practical benefit the astronomer enjoys from the special properties of large lenses which have just been enumerated.

Like other scientific men, astronomers who expect to accomplish much of importance at the present day find it necessary to specialize, and to devote their attention to certain classes of work in which long study and experience have given them particular skill. Thus it is that to some astronomers certain of the advantages of a large telescope appeal much more strongly than do others. In fact, in order to derive the best results from the use of the instrument it is necessary to have observations made with it by men who are capable of bringing out its best qualities in various kinds of investigation. Thus the first-mentioned property of rendering visible faint objects should be utilized by an astronomer who has gained much experience in searching for and measuring objects at the very limit of vision. One who has not given special attention to this class of work would be surprised to see in a large telescope certain of the faint stars or satellites of whose discovery he may have read. When the fifth satellite of Jupiter was discovered at the Lick Observatory by Professor Barnard, in 1892, claims were put forward by certain amateur astronomers who possessed small telescopes that they themselves were entitled to the honor of the discovery, for they had seen the satellite long before. Such claims might be taken in earnest by one unfamiliar with the instruments employed by the respective observers. But it is only necessary to examine this minute object with a 36-inch or a 40-inch telescope in order to appreciate the great merit of the discovery and the absurdity of such claims as have been mentioned. The tiny satellite is so faint that hitherto it has been seen with very few telescopes, all of them having large apertures. In its rapid motion close to the surface of the great planet it is completely invisible to an eye unprotected from the brilliant light of Jupiter. Even the close approach of one of the other satellites is sufficient to cause it to disappear. In measuring the satellite Professor Barnard finds it necessary to reduce the light of Jupiter with a piece of smoked mica, through which the planet is still clearly visible and easily measurable, though not annoying to the eye. Without an instrument like the Lick telescope the fifth satellite of Jupiter would never have been known. It may be interesting to mention here that Professor Barnard's recent measures of this satellite with the Yerkes telescope have shown that his original determination of the time of its revolution in its orbit, made five years ago at Mount Hamilton, was not in error more than 0.03 second. It was found that the time of elongation differed less than half a minute from the time predicted in the Nautical Almanac. The period is now known within a few thousandths of a second. In this connection, also, it is well to add that Prof. Asaph Hall's discovery in 1877 of the two small satellites of Mars was directly due to the advantage given him by the large aperture of the 26-inch telescope at the United States Naval Observatory.

Such small members of the solar system are by no means the only feebly luminous objects which great telescopes have brought to light. Faint stars in the close proximity of bright ones are usually beyond the reach of small telescopes. Thus the companion of Sirius was not seen until 1862, when the late Alvan G. Clark encountered it in his tests of the 18-inch objective now at the Dearborn Observatory, which was the largest glass that had been constructed up to that time. The small companion to Procyon, discovered not long ago by Professor Schaeberle with the Lick telescope, is another object of the same type. These are conspicuous examples of that great class of objects known as double stars, which consist of two stars revolving about their common center of gravity. From the third advantage of large instruments, to which reference has already been made, it will be seen that they are peculiarly adapted for the investigation of these binary systems, not only because of their power to show faint objects in the neighborhood of brighter ones, but also on account of their capacity to separate two closely adjacent stars which in a smaller instrument would be seen as one. Thanks to this property, many interesting binary systems whose components are exceedingly close together have been found by Professor Burnham with the Lick telescope, and, although he has devoted no special attention to a search for such objects, Professor Barnard has already encountered several of them in his work with the Yerkes refractor. From what the spectroscope has taught us of binary systems, we have every reason to believe that telescopes may go on increasing in aperture almost indefinitely without ever arriving at the possibility of separating into their component parts all existing double stars. As has been stated, the Yerkes telescope can show as distinct objects stars which are no farther apart than 0.12″ of arc, and on account of the elongation of the image a double star whose components are only 0.1″ apart can be distinguished from a single star. But there undoubtedly exist stars far closer together than this, some of which can be separated by an aperture of not less than 40 feet.

There has been much discussion in recent years regarding the relative advantage of large and small telescopes for observations of the markings on planets. I do not propose to enter into the details of this discussion, partly because my own investigations are primarily concerned with observations of another nature, and thus have not especially qualified me to form an opinion on this point, and partly on account of the fact that additional arguments in favor of large instruments would serve little purpose. It seems to me only necessary for an unprejudiced person to examine a planet first with a small telescope of from 5 to 15 inches aperture, and then to look at the same object with an instrument of 36 or 40 inches aperture, under identical atmospheric conditions. When the seeing is distinctly bad, that is, when the atmosphere is in so disturbed a state that the images are blurred and unsteady, the smaller instrument will assuredly show all that can be seen with the larger one. But with better atmospheric conditions, to my eye at least, the advantage lies wholly on the side of the larger instrument, whether the object be the moon, Jupiter, Mars, or Saturn. In the case of the moon particularly, much fine detail which I have never been able to see with the 12-inch telescope is clearly and beautifully visible with the 40-inch. I am certainly inclined to think that large telescopes are greatly to be preferred to small ones for work of this character. But I give much less weight to my own opinion on this subject than to that of Professor Barnard, who for many years has observed the planets with instruments varying in size from a 5-inch telescope to the 36-inch on Mount Hamilton, and the 40-inch of the Yerkes Observatory. He believes a large aperture to be immeasurably superior to a small one for these observations. This seems to me quite sufficient to settle the question, for it would be difficult to name a better authority.

One incidental advantage of such an instrument as the 40-inch telescope, which depends to a great degree upon the stability of its mounting, is the ease and certainty with which micrometrical measures can be effected. Since the telescope was first ready for regular use last September, Professor Barnard has made with it a long series of micrometrical measures, which have included such objects as the satellite of Neptune, the companion to Procyon, and the fifth satellite of Jupiter. The precision of these measures is most satisfactory, and lends special interest to an attempt which he has made to determine the parallax of the nebula N. G. C. 404, which is in the field with the bright star β Andromedæ. This object has a definite condensation, which permits its position to be accurately determined with reference to a number of stars in the neighborhood. A long series of measures, covering a period of five months, have led to the conclusion that the nebula can not possess a parallax as great as half a second of arc, and, therefore, can not be nearer the earth than about four hundred thousand times the distance from the earth to the sun.

Mention should be made of one more interesting observation by Professor Barnard, which would have been much more difficult with a small telescope. It will be remembered that in the valuable work which Professor Bailey has been doing at the station of the Harvard College Observatory in Arequipa, Peru, excellent photographs were obtained of southern star clusters, which show that these clusters contain an extraordinary number of variable stars. Not only do scores of stars in a single cluster vary in their light, but the change is exceedingly rapid, occupying in some instances only a few hours. So far as I know, none of these remarkable variations had been seen visually until Professor Barnard undertook the systematic observation of one of the clusters with the 40-inch telescope. On account of the large scale of the images, he is able to distinctly see stars in the cluster without confusing them with others in their neighborhood, and has thus been enabled to follow their changes in brightness. In this way he has confirmed the variability of many of the stars on Mr. Bailey's photographs. There are few more remarkable objects in the heavens than these magnificent star clusters, so many members of which are subject to fluctuation in their light. Professor Bailey's discovery is the more noteworthy considering the fact that such an object as the great cluster in Hercules contains not more than two or three variable stars, while the Harvard plates show that the cluster Messier 3 contains 132 variables. This is only one instance out of many of the striking efficiency of the photographic work which is being carried on under Professor Pickering's able direction.

It may be well to introduce here a few words regarding the magnifying powers employed in actual observations. The optimistic writer who is planning to photograph houses on Mars believes that his recent invention will render possible the use of powers as high as a million diameters, and even greater, so that if men exist upon the planets they can easily be seen. Astronomers know nothing of such powers in practice. For double-star observations, with the largest telescope and under the most perfect conditions, powers as high as 3,700 diameters have occasionally been used. But in regular work it is not a common thing to exceed 2,700 diameters. Under very exceptional circumstances the moon might perhaps be well seen when magnified 2,000 diameters, but this would be an extreme case, and in general a much better view could be had with powers ranging from 500 to 1,000. Jupiter can rarely be well seen with a power greater than four or five hundred, though Saturn will stand considerably higher magnification. Mars is best seen with a power of five or six hundred. With small telescopes lower powers are generally used. The difficulty is not in finding optical means to increase the magnification, as some of these newspaper writers seem to imagine. It is rather a question of being able to see anything but a confused luminous object after the high eyepieces had been applied. The more or less disturbed condition of the earth's atmosphere is mainly responsible for this, but it is doubtful whether, with even perfect conditions, such an object as Jupiter could be advantageously submitted to great magnification.

During the present century there has grown up side by side with astronomy, to which it in fact owes its existence, the new science of astrophysics. In a broad sense this science may properly be classed as a department of astronomy, but at the present time its interests are so manifold, its methods so distinct, and its relationship to pure physics so pronounced, that it may fairly claim to be considered by itself as a coordinate branch of science. While astronomy deals more especially with the positions and motions of the heavenly bodies, it is the province of astrophysics to inquire into their nature and to search out the causes for the peculiar celestial phenomena which the special instruments at the disposal of the astrophysicist bring to light. It should be added that no hard and fast line can be drawn between astronomy and astrophysics, as one of the principal problems of the latter subject involves just such determinations of motion as are particularly to be desired for the purposes of the astronomy of position. The subjects are thus intimately related and closely bound together, and the bond between astrophysics and physics is hardly less strong. They should thus be cultivated together, so that they may mutually assist one another in bringing about the solution of the varied problems with which they are concerned.

It is particularly in astrophysical research that a great telescope is advantageous. For the principal instrument of the astrophysicist, the spectroscope, it is necessary to have as much light as can be gathered into a single point. With sufficient light the chemical analysis of the most distant star resolves itself into a comparatively simple problem. But with small telescopes, and consequently faint star images, such analysis, except of a roughly approximate character, is impossible with the less brilliant stars.

One of the principal problems of the astrophysicist is to determine the course of celestial evolution. It has been found that the spectra of stars are susceptible of classification in a few well-defined types, which seem to correspond with different periods in stellar development. Starting from the great cloudlike masses of the nebulæ, it is supposed that stars begin to form in regions of condensation, and that the great masses of gas and vapor continue to contract under the action of gravitation, meanwhile radiating heat into space. It is known from theoretical investigations that such cooling gaseous masses not only continue to grow smaller; they also rise in temperature with the advance of time. Finally a certain point in their career is reached when the rise in temperature ceases, though the contraction of the mass is not arrested. The balls of condensing vapors continue to cool, losing more and more heat, and becoming smaller and smaller in diameter. It is perhaps at about this period in their history that they pass through such a stage as is now exemplified by the sun, which has presumably cooled from the condition of a white star like Sirius to that of a star of the second or yellow class. The spectra of such hot stars as Sirius contain little more than dark and exceedingly broad lines, grouped in rhythmical order and due to the gas hydrogen. As these bodies continue to cool, the strong lines of hydrogen become less prominent, and lines due to metallic substances begin to appear. These become more and more striking, until finally we reach such a type of spectrum as that of Procyon, which is intermediate in character between the Sirian and the solar stars. From this point on we find a continual approach to the solar type, until at last stars are reached whose spectra agree line for line with that of the sun. After passing through the condition of the central body of the solar system, the yellow and orange color of the stars becomes more pronounced, and subsequently a reddish tinge appears, until finally stars of a deep red color are found, which seem to mark the last stage of development before complete extinction of light. Through a part of this line of evolution it is easy to trace the changes in stellar spectra, the solar lines still continuing to be present, and superposed upon them a remarkable series of flutings which are characteristic of these reddish stars of the third class. But between such stars and those of the class which Vogel has designated as IIIb there seems to be a break in the evolutionary chain.

Stars of Class IIIb are of an orange or red color, and with the telescope alone some of them can not be distinguished in appearance from the more fully developed stars of Class IIIa. But in the spectroscope they are entirely different. All of these objects are extremely faint, the two brightest of them being hardly visible to the naked eye. For this reason but little has been learned of their spectra, although the spectra of stars like Vega and Arcturus, which are some scores of times more brilliant, have been carefully investigated by both visual and photographic means. According to Dunér and others, the spectrum of the star known as 152 Schjellerup consists of certain heavy, dark bands, which coincide closely in position with bands given by compounds of carbon, and, in addition to these, a luminous zone in the orange portion of the spectrum. Three or four of the most intense solar lines have also been detected in these objects. But beyond this it is impossible to go with the appliances used in the earlier investigations, although it may well be that photographic methods would have greatly changed the character of the results obtained.

During the past winter a photographic study of the red stars has been rendered possible by the 40-inch Yerkes telescope. Photographs of the spectra of many objects of this class have now been obtained, and many lines which were not previously recognized on account of the faintness of the spectrum in small telescopes have been recorded. In the case of two stars of Class IIIb, 132 and 152 Schjellerup, the spectra have been photographed with a powerful spectrograph containing three prisms, giving high dispersion and considerable precision to the measures. It has been found that among the most characteristic features of these spectra are numerous bright lines, some of which seem to have been glimpsed by Secchi in his pioneer work at the Collegio Romano, though his drawings do not correctly represent their appearance or position. In fact, he recorded bright lines where none exist, and failed to record others, among which are the brightest in the spectra. Both Dunér and Vogel, who are certainly to be regarded as the best authorities on the subject, altogether deny the presence of bright lines. And had my own observations been confined to an examination of the spectra with the instruments used by these observers I would unhesitatingly subscribe to their opinion. But the great light-collecting power of the 40-inch telescope renders the detection of the bright lines a comparatively easy matter. Even with this instrument, visual observations with the low-dispersion spectroscopes used by Dunér and Vogel would hardly show them, but they are easily seen with a three-prism spectroscope, and they have been repeatedly photographed with one and with three prisms. Some of these photographs have been measured and the wave lengths of the bright and dark lines determined. A comparison of the results with those obtained for other types of stellar spectra suggests certain interesting relationships, which, if confirmed by subsequent work, will be of service in tracing the course of stellar evolution.

This is only a single instance of the advantage for stellar spectroscopic work of the great light-collecting power of large telescopes, but it would be easy to multiply examples. Our knowledge of the peculiar spectra of the stars of the Wolf-Rayet class, all of which are found in the Milky Way or its branches, is due in large part to the visual and photographic study of these faint objects made by Professor Campbell with the Lick telescope. In the able hands of Professor Keeler, whose recent election to the directorship of the Lick Observatory is so truly a cause for congratulation, the same powerful instrument rendered possible the determination of the motion in the line of sight of the planetary nebulæ. We may well be confident that the future record of the great telescope on Mount Hamilton will be marked by many similar advances.

I might profitably go on to speak of the advantages of large telescopes for the study of the sun, for in no field of research can they be better employed. In photographing the solar faculæ with the spectroheliograph the large image given by a great telescope is particularly useful for purposes of measurement, as well as for the study of the form and distribution of these phenomena. Prominences, too, whether of the quiescent or eruptive class, are best photographed on a large scale. With a large image it may also become possible, under good atmospheric conditions, to photograph some of the delicate details in the chromosphere, which, with a small solar image, would be wholly beyond the reach of the photographic method. It is probably in the study of the spectrum of the chromosphere, however, that one best perceives the advantage of a large instrument as compared with a small one. Recent experience has made this very clearly evident, for with the 40-inch Yerkes telescope it has been possible to see in the chromospheric spectrum a great number of faint bright lines which were wholly beyond the reach of the 12-inch telescope used in my previous investigations. In this way it has been found that carbon vapor exists in the vaporous sea which covers the brilliant surface of the photosphere.

It will be admitted, I think, from what has been said, that great telescopes really have a mission to perform. While, on the one hand, they are not endowed with the almost miraculous gifts which imaginative persons would place to their credit, they do possess properties which render them much superior to smaller instruments and well worth all the expenditure their construction has involved. In answering the question, "Do large telescopes pay?" it is simply a matter of determining whether the work which can not be done without the aid of such telescopes is really worth doing. No one who is familiar with this work is likely to deny that it is worth all the money and time and labor that can be devoted to it. I therefore confidently believe that the generous benefactions which during the last quarter century have permitted the erection of large telescopes in various parts of the world have been wisely directed, and that further sums might well be expended, particularly in the Southern Hemisphere, in the establishment of still more powerful instruments.

THE LE SAGE THEORY OF GRAVITATION.

[Translation by C. G. ABBOT, with introductory note by S. P. LANGLEY.]

INTRODUCTION.

Le Sage's paper is one much oftener referred to than directly quoted from or read, and this is partly because the original is very little known, although it is in no more obscure a place than the Memoirs of the Berlin Academy, printed in the year 1684.

Le Sage appears to have been one of the academicians who, though in the capital of Prussia, were bound to write French of any sort rather than German, and it is only fair to the present translator to say that certain passages of the original hold the meaning of the author so securely hidden that it is doubtful if anyone could render them into English with entire confidence that their whole meaning had been grasped. Whatever the original obscurity, however, the translation, I believe, means something definite and, I hope, true.

The reader will recall that at the time when Le Sage wrote, the corpuscular theory of light was universally accepted, the laws of the conservation of energy and of matter were as yet unknown, and the kinetic theory of gases was quite beyond the scientific horizon. Hence it is a matter for surprise, not that Le Sage introduces in explanation of the difficulties met with hypotheses now in a form appearing somewhat crude, though doubtless still conceivable, but rather that his statement requires so little modification to fit it to the thought of the present day.

Some of the great objections made to Le Sage's theory, such as the supposed impossibility of this shower of his atoms acting with equal effect in the interior of the densest bodies as on the surface, are made in probable ignorance of how entirely satisfactory the hypothesis of the author is in this respect; I mean so far as the use of the mathematical infinity can render it so; while other difficulties have been, if not cleared up, at least rendered less formidable by the advance of modern knowledge, which is on the whole clearly making more for the hypothesis than against, if we put it in the form in which Le Sage would doubtless put it were he living now.

Thus the objection of the hypothesis of countless atoms coming from and going to infinity, to the dissipation of their kinetic energy into heat upon impact with solids—this latter class of objections seems to have been very generally met in recent years. Thus it has been made evident that the particles in question could vibrate in long closed paths with the same effect as if they came in from outer space and returned to it in straight lines, as the author originally supposed; and as to their infinitesimal smallness, our purely physical conceptions of space and even of time are not only still, as is well known, relative, but have received a curious extension since Le Sage wrote, so that our limit of the physically infinitesimal has been pushed farther back by studies into the nature of the molecule and the atom until we have before us actual things of an order of magnitude incomparably below anything known to the physicists of our author's time.

On the whole, then, the tenor of modern thought goes in the direction in which we are led by this theory, if by that we understand it, not in its first crude enunciations, but with the modifications which can now be legitimately associated with it, and which tend to make it both more suggestive and to maintain a continued interest in it—an interest which seems to justify the present publication of a paper with which so few are familiar at first hand.

S. P. LANGLEY.

THE NEWTONIAN LUCRETIUS.[1]

By M. Le Sage.

[Read by M. Prevost at a meeting of the Berlin Academy in 1682.]

"In all branches of knowledge the earliest systems are too limited, too narrow, too timid; and it would even seem that the prize of truth is only won by a certain audacity of reason."—Fontenelle, in eulogy of Cassini.

THE AIM OF THIS MEMOIR.

I propose to show that if the earliest[2] Epicureans had possessed as just ideas on cosmography as those of several of their contemporaries, which they neglected, and but a portion of the knowledge of geometry which had then been attained, they would in all probability have easily discovered the laws of universal gravitation and its mechanical cause. Laws, whose discovery and demonstration are the greatest glory of the mightiest genius that has ever lived; and cause, whose comprehension has long been the object of ambition of the greatest physicists, and is now the stumbling block of their successors. Such things, for example, as the famous Kepler's laws—discovered scarcely two centuries ago, and founded in part upon gratuitous conjectures and in part upon tedious gropings—would have been nothing but special inevitable corollaries of the general knowledge which the ancient philosophers could easily draw from nature's own mechanism. This conclusion is entirely applicable to Galileo's laws on falling bodies, whose discovery has been still slower and more contested. Moreover, the experiments by which this discovery was established were so crude that they left the way open to interpretations which rendered them equally compatible with several other hypotheses,[3] which were in fact urged against him. On the other hand,

[1] Translated by C. G. Abbot from Nouveaux Mémoires de L'Académie Royale des Sciences et Belles-Lettres. Année, MDCLXXXII. A Berlin, MDCLXXXIV, pp. 404–427.

[2] I say only the earliest; for after a system has survived several centuries it leads men to the one or the other of two extremes. Some reject everything pertaining to the system disdainfully, while others, on the contrary, embrace reverently all its traditions, without offering to make the least correction. It is this latter faction who have adopted the atoms of Epicurus, Lucretius, Gassendi, and all the intervening Epicureans. * * *

[3] One of these hypotheses was that the total time being as the arc of a certain circle, the total distance fallen through was as the versed sine of this arc. Now if the magnitude of this circle had been better chosen, I do not see how one would be able to refute this hypothesis, starting from the simple phenomena.

the consequences of the theory of atomic collisions would have been unequivocally in favor of the sole right interpretation (equal accelerations in equal times).

The union of the several branches of this conclusion forms not only a philosophic truth of extreme interest, but one from which a very useful consequence may be drawn, which is that in spite of the greater weight due to a posteriori researches a priori ones are not to be wholly neglected, since they may greatly accelerate the success of the former. Already some impartial philosophers are agreed that such conjectures if lucid and capable of evaluation might be useful to the most rigorous physicists, were it only in suggesting to them definite points of view from which to direct experiment, in the place of that indecision in which the mere vague wish for new investigation has often left them.

Let us clearly understand that such speculation is only permissible for the sake of occupation when the skill and patience which new observation and experiment require are lacking. We ought to be thoroughly informed as to all previous observations and experiments on the subject and to keep these steadily in view in forming hypotheses, which are to be tested by them with the aid of every help that mathematics can give in examining as to the exactness of their agreement.

Finally, it is such an agreement rather than any elaboration of method which brings conviction to most students of any physical theory, and this whether they are aware of this agreement before their acquaintance with these methods or whether a study of the method led them to the agreement.

I.

If the disciples of Epicurus had been as fully persuaded of the sphericity of the earth[1] as they were of its flatness,[2] then instead of conceiving their atoms to move in nearly parallel paths, as was suited to a directive force perpendicular to a plane surface, they would undoubtedly have attributed to them motion normal to the surface of a sphere, and consequently directed at all points toward its center.[3] An example of such a condition as I have in mind would be furnished if it hailed simultaneously in all the countries of the earth.

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[1] Plato and Aristotle had discoursed at great length upon the sphericity of the earth; Archimedes and Aristarchus had assumed it; Thales and Zeno had taught it, and all the astronomers believed it. (See the Timæus of Plato, the close of the second book of Aristotle upon the Heavens, the Hour-Glass of Archimedes, and the tenth chapter of the third book of Plutarch upon the Opinions of the Philosophers.)

[2] Neither Epicurus nor Lucretius discovered the figure of the earth. But it seems probable that they conformed to the opinions of Democritus upon all questions where they did not expressly oppose him. Moreover, Gassendi (in his Commentaries on Epicurus, p. 213 of the edition of 1649) alleges strong reasons for believing that they supposed the earth's surface to be flat.

[3] Instead of which they entirely rejected this centripetal tendency.

II.

The following objection would of course have been raised by some to this view: Part of these atoms must necessarily encounter the moon before reaching the earth, and by their pelting would push her toward us; and on the other hand the force exerted upon those terrestrial objects which she shields would be less because of her interposition. Consequently we ought to see the moon descending and a part of the waters of the ocean rising to meet her, as if rendered lighter by the interception of the atoms, and consequently yielding their place to the adjacent waters.[1] In view of these objections the Epicureans would have had to see if some phenomenon of this nature did not really exist. They would have answered their opponents that the moon did not recede from us on a tangent, but really did approach the earth at each instant, and that the alternating motions of the ocean, so accordant with those of the moon, exhibited this very effect in question, due to the inequality introduced in the stream of atoms by the interposition of this great body.

III.

The example of a pebble projected horizontally, which circulates for a few moments about the earth before falling, and longer in proportion as the motion is more rapid, would have made it clear that the moon, which occupies but a month in such a great journey, might not of necessity actually approach the earth except in the sense of being nearer than if she had gone off on a tangent.

IV.

A persistent antagonist, fortified by some theorems of centrifugal force similar to those of Huygens (which are easily demonstrated by elementary geometry for polygonal orbits such as would result from intermittent collisions) might further have objected that the motion of the moon was still 60 times too slow[2] to prevent her actual approach to us, taking into consideration the very considerable force of gravitation found at the surface of the earth. Upon this the Epicureans would not have been slow to reply that since the distance from the

[1] This is not precisely the actual state of affairs, but it is thus that the case would present itself at first view. As an exact recognition of the laws of this phenomenon would be more slowly acquired than an exact knowledge of the laws of atomism, there would never be a time when that theory would have been found at fault in this respect.

[2] If the force of gravitation were the same at all distances, the period would be reciprocally proportional to the square root of the distance (Hugenii Theor. IV.) instead of to the three halves power as follows from the Newtonian law (Phil. nat. Princ. Math. Prop. IV. Cor. 6). Then the period of the moon, as compared with that of a body revolving at the surface of the earth, would be expressed by $\sqrt{60}$ instead of $60\sqrt{60}$, the value derived from the Newtonian law of gravitation.

moon to the center of our globe is 60 times as great as our distance from this same center, the spherical surface having the radius of the moon's orbit is 3,600 times as great as that of the earth. So that if the outer surface were traversed by the same number of atoms as the inner, their distribution would be 3,600 times rarer, and they would in consequence cause a gravitation 3,600 times less. This would be exactly that required by the theorems,[1] for this gravitating force would suffice to sustain at a distance 60 times as great a moving body whose absolute velocity was $\sqrt{60}$ times less than that required by a body revolving at the surface of the earth.

V.

The parallelism of path which Epicurus had introduced in the atomic theory of Leucippus and Democritus was not exact, since had it been so these atoms, all moving with equal velocity, could never have come in collision. But Epicurus required that they should collide in order that he might explain the formation of compound bodies without assuming the intervention of a superior cause. Hence he supposed the paths of the atoms to be slightly inclined to each other, and it is well known that the introduction of the correction subjected him to many pleasantries and objections from philosophers of other sects.

VI.

If, however, Epicurus had embraced the doctrine of the convergence of the atoms toward a center, undoubtedly his opponents would have attacked this hypothesis quite as vigorously. The Epicureans in replying would have been able[2] to explain this convergence by returning to the system of Leucippus and Democritus as follows: Imagine the atoms to move fortuitously in every direction, and let us trace the result in

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[1] Combine the second and third theorems of Huygens published in 1673 following his Horologium oscillatorium.

[2] It was natural enough to greatly diversify this motion which tended to deflect the atoms.

Lucretius, even, despite his devotion to Epicurus, expressed himself several times conformably to the system of Democritus. His first book with the first 216 lines of the second ignored the imperfect parallelism that he lent to the paths of the atoms, for instead of speaking of this parallelism he seems to say three times that they come from all directions (undique, lines 986, 1041, and 1050), that they waver (volitare, 951), trying several kinds of collisions (multimodis plagis, 1023 and 1024), essaying all kinds of movements (omne genus motûs, 1025), finding room to advance in whatever direction they move (motûs quacumque feruntur, 1075). He adds, in the second book, that they wander in space (per Inane vagantur, line 82), that they are agitated by various movements (varioque exercita motu, 96), and that all those which have not been able to associate themselves together to form great masses are always agitated in the great void (in magno jactari semper Inani, 121) in the same way as the dust that one sees in a dark chamber into which the sun's rays penetrate is moved about in all directions (nunc hùc nunc illùc, in cunctas denique parties, 130). Finally, several of his commentators convey the same idea.

the case of a body near the earth. All the atoms coming toward the body from the direction of the earth would be cut off by it, while from all other directions the body would be subjected to uninterrupted bombardment. Consequently there would be a resultant motion of the earth, that is in the line of diminished resistance, and this resultant motion would be exactly the same as if the bombarding atoms all converged toward the earth's center instead of moving fortuitously.

VII.

The Epicureans would have even seized with avidity upon this occasion to give an air of disorder to the primitive movements of the universe. For this would accord the better with their system of the origin of things (otherwise sufficiently absurd and impious) that there was no appearance of parallelism, perfect or imperfect, whereas all tendency to parallelism would appear to be the result of some particular design, and consequently to indicate the operation of some intelligent being.

VIII.

I speak of disorder in connection with primitive movements only. The resultant motion of bodies having inertia would be directed toward the center of our globe with great exactness, in consequence of the combination of a vast number of impulses in different directions. For it is a well-known result of the doctrine of chances that minor irregularities, when in great number, mutually compensate each other exactly, so that each several inequality becomes imperceptible in its effect upon the resultant.

IX.

Still another consideration would have led the atomists to make this same modification of the direction of motion of the gravitational atoms. All will agree with me that they were certain to have met with one or other of these two objections or to have themselves raised them. As the earth revolves without cessation about the sun,[1] the hypothesis that

[1] Democritus was a century and a half later than Pythagoras, who had secretly taught the revolution of the earth. He might even have seen Philolaus who more openly proclaimed it, and Timæus who appears to have had the same belief. He ought also to have been informed of the opinion of the Pythagoreans upon the subject, for Heraclides had been of this sect before he listened to Plato and Aristotle, and he maintained at least that the earth rotated about its center. According to the report of Diogenes, Laertius. and of Porphyry, Democritus had attended the teaching of the Pythagoreans; and besides, the Eleatic sect (if one may credit Strabo) was nothing but an offshoot of the Italic. Finally, the atomists, following Democritus, would have had opportunity to be even better instructed than he in regard to the earth's motion. For this doctrine was supported by a multitude of philosophers of all countries, among whom the principal names, in addition to those already cited, are Archimedes and Nicetas, of Syracuse; Aristarchus and Cleanthus, of Samos; Architas, of Tarento; Seleucus, Eophantus, and even (according to Theophrastus) Plato in his later years.

all the atoms are directed toward the center of the earth would have required that each new shower of atoms must seek it in a different direction from that followed by the shower next preceding, a condition not in accord with the predilection of the sect of the Epicureans for the operations of chance, nor with their antipathy for occult qualities

X.

In order to extricate themselves from this difficulty the atomists would necessarily have rejoined that there was no place in the heavens, equal in dimension to the earth, toward which there did not advance in a given time quite as many atoms as our planet encounters in the same portion of time, and that these other atoms were in motion exactly like those encountered by the earth. Not that there was any particular relation between places and the streams setting toward them, but, since it was essentially a confused movement, equal areas must naturally intercept, one equally as much as another, the paths of the atoms which blindly traverse space; and in consequence they must be equally exposed to their visits.

XI.

When once the Epicureans were thus come to explain the matter so neatly, the most thoughtful and curious among them would certainly have followed out the consequences which could be easily deduced from this hypothesis, and they would necessarily have arrived at the following propositions:

1. The atoms which pass to one side of any central body contribute nothing to the force of gravitation which it exercises toward other bodies, for such atoms are exactly counterbalanced by direct antagonists. Gravitation would be due solely to those atoms which are fortuitously directed toward the central body. As we have seen, the resultant action of these atoms is everywhere directed toward the central body, like the rays of light converging toward a focus when assembled by a convex lens or a concave mirror. Hence, it is proper to apply to them what has been proven in Paragraph IV touching the terrestrial gravitation; that is to say, their gravitational effect is inversely proportional to the square of the distance of the attracted body from the central body.

2. The gravitational atoms are directed not only toward the centers of the greater bodies, but toward each of their particles as well, since they move indiscriminately in all directions in space. The atoms, moreover, act effectively in those directions in which their antagonists are intercepted; that is to say, in all directions in which there are particles of matter. Therefore they tend to move the heavy masses which they encounter not toward the heavenly bodies in gross, but toward each of their particles in detail. Hence the gravitation of masses toward the center of a celestial body is nothing but the result-

ant of an imperceptible movement of the masses toward all parts of the great body (as, from certain passages of Cicero and Plutarch, it appears had been before supposed by some of the ancients). Consequently this gravitation would be proportional to the number of the particles; that is to say, to the mass of the central body.

Now from these two propositions alone there might have been deduced synthetically the entire theory of universal gravitation without further mention of gravitational atoms.

XII.

This is the place to insert a certain proposition which is commonly spoken of as if it were distinct from those which teach that gravitation is universal, but which appears to me to be included in that expression. I refer to that which affirms that gravitation is mutual or reciprocal; or, in other words, that it is subject to the ancient law of mechanics, which states that action and reaction are equal.

I say that this is the place to consider this proposition, because it can equally well be proved either through the introduction of the agent of gravitation, as I have done in preceding paragraphs, or by considering gravitation abstractly, as I shall do in those which follow. This proposition therefore forms, as it were, a gradation between those which I have established by the first method and those which I shall establish by the second.

First method: Inasmuch as one body is pushed toward another by the atoms which the second body has deprived of direct antagonists, while the latter body is pushed toward the former by these same antagonists, the two bodies are necessarily pushed toward each other with equal force, whatever be the inequality of their masses or the differences in their forms.

Second method: Since each particle of one of the two bodies tends toward every particle of the other, the first body is urged toward the second with a force proportional to the number of particles which the second contains, or, in other words, with a force proportional to the mass of the second. Furthermore, since the impetus or momentum of the first body is the summation of the impetus of its separate particles, it is proportional to the total mass of the first body. Thus it follows that the impetus of the first body is proportional to the product of the masses of the two bodies.

By a similar train of reasoning the impetus of the second body is also proportional to this product. Therefore the usual bodies are urged together with equal forces.

XIII.

I am now in a position to examine what other consequences the ancients would probably have drawn from the principle of a mutual gravitation directly proportional to the masses and varying inversely as the square of the distance. For the sake of brevity the mechanical cause may be left out of consideration in the discussion.

As these philosophers would have foreseen many difficulties in rigorously testing every consequence to see if it coincided exactly with observation, and would therefore have refrained from embarking upon so serious a task before perceiving that the deductions accorded in gross with the results of experience, I presume they would not seriously have applied geometry and computation to this gravitation without having first determined by simple reasonings what, approximately, would be the effects flowing from it, and seeing that these conjectures accorded roughly with the real constitution of the universe[1] I believe I do no violence to probabilities in presuming that the ancient philosophers would have been acquainted with some such reasonings. Having fewer matters than we to distract their attention, they were able to make very exact deductions in subjects requiring nothing but meditation. With reference to the acquired knowledge which would be needed in such reasonings, it will be recalled that the theory of conic sections had been discovered and cultivated before the birth of Epicurus, that Archimedes had made great advance in the doctrine of centers of gravity, and that the ancient geometers, and especially the last named, employed approximations with great ingenuity when they were unable to attain to rigorous precision.

XIV.

Encouraged by these first successes and animated by the grandeur of the enterprise it is highly improbable that these ardent and subtile geometers[2] would have stopped here. They would doubtless have invented for the purpose some means for passing from the ratio of sensible quantities to that of their imperceptible elements, and conversely from elementary quantities to their summation, at least for the simple case required when one wishes to avoid the numerical computation of the small anomalies of the movements of the celestial bodies.

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[1] I had intended to insert here some preliminary observations which the atomists would probably have made. I had collected them in part from various researches (or incidental points) made by good geometers who have undertaken to illustrate to readers but little advanced in mathematics some of the truths of physical astronomy. The remainder were from notes of lectures which I have myself given upon these matters. But I have omitted this digression on account of its length. Perhaps I may be permitted to remark that these elementary tests may be rendered very convincing, although some of them presuppose so little knowledge of geometry that they may even be stated without reference to figures.

[2] It should be borne in mind that we are not here speaking of the Epicureans as some have really been—that is to say of a nature decidedly lazy and consequently ignorant of astronomy and physics—but of philosophers simply, Epicureans as respecting the fundamental propositions of physics only, but resembling rather their contemporaries of other sects in general enlightenment and taste for research. Such a supposed character for these philosophers is by no means forced, since the physical and speculative dogmas of Epicurus did not necessarily entail his moral precepts and practices.

Certainly they had sufficient patience and sagacity to succeed in finding such a method, since they had had enough of these qualities to discover and advance in considerable degree the admirable doctrine of incommensurables, and of exhaustions, although these were not ordinarily used except in the consideration of the five regular bodies, and were specially derived, it is said, to examine certain very hazardous and even fantastic conjectures of the Pythagoreans and Platonists.

XV.

Practically, if one omits from the theory of central forces those curious propositions and generalizations which can only be regarded as its luxuries, as well as the delicate evaluations which are required only for the perfecting of astronomical tables, all the rest may be demonstrated sufficiently for the uses of the physicist by the aid of lemmas less exact and universal than those of the calculus.

This has indeed been pointed out in some degree by several geometers, but it may be realized still further if the reader will undertake by the same or analogous means of simplification to attack other propositions than those already so treated.

But the probability that the ancients would have been able to accomplish such demonstrations is still less necessary to the plan which I have proposed to myself, as stated at the beginning of this essay, than the probability that they would have discovered the simple relations mentioned in the thirteenth paragraph. Consequently the reader may, if he prefers, ignore the last three paragraphs and give attention only to matters which I have expressly engaged to establish.

XVI.

I declared that the laws of Kepler were necessary consequences of the doctrine that gravitation results from the impulsion of atoms moving in every direction, since Kepler's laws follow directly from those of Newton. I ought, however, to show, for the benefit of readers less versed in the matter, where it may be found proved that the first-mentioned laws are the natural consequences of the second.

First. That the law of areas proportional to times is a necessary consequence of gravitation, always directed toward a single point, is demonstrated by elementary geometry in the first proposition of Newton's Principia.

Second. That the law of squares of periodic times proportional to the cubes of the distances, for bodies appearing to describe circles, must necessarily follow from a gravitation inversely proportional to the square of the distance constitutes the second part of the sixth corollary to Proposition IV of the same work, and may be demonstrated by elementary methods also for regular polygons, which represent more nearly than exact circles the orbits traversed by bodies diverted slightly from their paths by intermittent collisions.

Third. That the ellipticity of an orbit is the necessary consequence of gravitation directed toward its focus, and reciprocally proportional to the square of the distance, is the converse of Proposition XI of the same book. This proposition has been more simply demonstrated as a consequence of the fiftieth of Book III of the conics of Appolonius.

I may pause here, since in maintaining that the laws of Kepler are an easy consequence of the system of atoms I have not pretended that their application to complex cases readily follows from the slight knowledge of geometry possessed by the ancients. Nevertheless, I may add—

Fourth. That the Proposition XI of the Principia once attained it does not appear to me difficult to establish the fiftieth, which extends our second consequences to ellipses—that is to say, which proves that in ellipses as well, the squares of the periodic times about an attracting body (placed in one of the foci) are proportional to the cubes of the mean distances.

XVII.

Let us now see how the laws of Galileo may be derived from the hypothesis of the impulsion of the atoms.

The blows of corpuscles, moving with a velocity more rapid than light, upon a body which has fallen three or four seconds, would be sensibly of the same strength as the preceding blows had been upon the same body when it had only fallen one or two seconds.[1] Hence the successive accelerations of the body in equal times must be sensibly equal, and the velocity at any instant must be sensibly proportional to the time elapsed since the beginning of the fall. From this it follows necessarily that the spaces traversed since the beginning are sensibly proportional to the squares of the total times,[2] and will be sensibly proportional to the succeesive odd numbers.

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[1] To assign to these corpuscles the velocity of sound even would be sufficient. For the velocity of sound is more than thirty-four times as rapid as that of a body which has fallen one second, or more than seventeen times as great as that of one that has fallen two seconds, etc. Hence with the increasing velocity of the falling body the accelerating impulses impressed by the corpuscles would be more feeble than at the beginning of the fall by one thirty-fourth at the end of one second, by two thirty-fourths at the end of two seconds, etc. This gradual decrease of acceleration would not be perceived in the longest times of fall which are ordinarily measured. How much less therefore would they be perceived if we assume for the corpuscles the velocity of light, which is nine hundred thousand times as great as that of sound.

[2] Demonstration: I divide the two times which are to be compared into an equal number of parts, so small that the body may be conceived as falling with equal rapidity during the whole duration of one of these parts. And I observe that the two bodies which are compared will have, at the beginning of each of the corresponding parts of the two times, velocities proportional to the times then elapsed, and consequently to the entire times. Hence the small spaces traversed at these corresponding instants will be traversed with a velocity proportional to the times compared.

But the elementary spaces fallen through will be proportional not only to the velocities with which they are traversed, but also to the portions of time occupied in traversing them, and consequently to the whole times. Therefore the small cor-

XVIII.

These synthetic demonstrations of laws of falling bodies by the introduction of mechanism whose existence is only surmised, may perhaps be less philosophical than analytic demonstrations which are based entirely upon observed phenomena. Still it must be recalled that in cases where direct observation has been difficult and inexact, error has frequently attended deductions of this latter kind. At all events the former kind of demonstration is much more philosophical than a gratuitous hypothesis, which is, nevertheless, the means of invention employed by Galileo; and its results are quite as well established as are the laws of Galileo since they are proved by exactly the same means, that is by the sensible accord of their consequences with the phenomena. Nothing else than this is claimed by Galileo himself and his principal successors.

XIX.

But the atomists would have encountered one very serious objection, to which they were necessarily exposed in common with all physicists who undertake an explanation of gravitation. For by having thickness a roof receives not a whit more of hail, or a shield of arrows; whereas, remaining otherwise unchanged, the weight of all bodies is augmented in direct proportion of their thickness. Conversely when one removes a heavy body from a shop or dwelling, or reduces it to sheets exposed without protection to material influences (the rain, for example) it receives more than when protected or concentrated so as to present a small surface. But it has never been found by merchants and artisans, who are continually in the habit of weighing, that bodies appear heavier in open air than when under cover, and gold-beaters have never perceived that the weight of the metal augments in proportion to the increase of its surface.

In a word, if the collision of atoms is the cause of heaviness, the weight of bodies ought to be proportional to their surface (or rather to their horizontal projection). How, then, does it happen that the weight is proportional to the mass?

Do the gravitational atoms then act across the thickest and most compact envelopes of all substances as fully as through the air? And

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responding spaces will be proportional to the squares of the whole times, and the sums of the (equally numerous) small spaces—that is to say, the whole distance traversed—will also be proportional to the squares of the whole times.

Remark: The assumption with which I started, and which is tacitly made in the other demonstrations of this law, is a sort of license equivalent to supposing that the parts of the times and spaces are infinitely small, and is less conceivable than one is accustomed to suppose. It is an inevitable inconvenience of the common hypothesis of the continuity of the action of gravitation. But this inconvenience is not encountered when we substitute the hypothesis of discontinuity. I mean to say that there arises no contradiction when the time increments are taken equal to the intervals between the blows of the gravitational agency.

does not the very sensible weight which they impart to these envelopes demonstrate the contrary, that is that all substances arrest the passage of a great number of corpuscles?

XX.

To this the Epicureans would have been forced to respond that the atoms doubtless traverse very freely[1] all heavy bodies; as freely, for example, as light passes through diamond and magnetic matter through gold, though one of these bodies is the hardest and the other the heaviest of all known bodies (which shows that they are less porous than most substances). Thus the number of atoms which are intercepted by the first layers of a heavy body would be absolutely insensible relatively to the number of those which pass through the last layers.[2] Nevertheless, the relatively small number intercepted would produce a sensible action upon the body, since they have, in virtue of an immense velocity,[3] the force of impact which they would lack by reason of their small mass.

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[1] Several ancient physicists recognized the pores in bodies. It may be seen, for example, in the eighth chapter of the first book of Aristotle on Generation and Corruption, that Empedocles, Leucippus, and Democritus had made a great deal of use of them to explain sensations and mixtures. Galen reports in his works on the Natural Properties, that Erasistratus (the grandson, it is believed, of Aristotle), a celebrated corpuscular physician who denied attraction, believed in the existence of a vacuum and attempted to reduce all natural properties from the size of the pores. Coelius Aurelianus speaks of them also in connection with Asclepiades, of Bithynia, a physician of the time of Pompey. And Sextus Empiricus assures us that not only Asclepiades but also other physicians and physicists of the sect of Epicureans made many applications of the pores. Finally, in the first book of Lucretius there are ten or twelve lines upon the great permeability of bodies, concluding as follows: Usque adeo, in rebus, solidi nil esse videtur.

[2] However considerable we assume the number n of horizontal layers going to compose a body of uniform density, the number (and consequently the effectiveness) of the gravitational atoms is diminished in passing each one of them, because some atoms are intercepted by the solid material composing the layer. The number of atoms transmitted by a layer, and remaining effective to produce weight in the next lower one, will bear the same ratio to the number reaching the first that the volume of the spaces or pores in the layer bears to its total volume. Assuming the body to be of uniform density, this ratio will be constant, and since the weight of each layer is proportional to the number of atoms available to collide with its substance, this ratio represents the relative weight of any layer to that next above it. However nearly equal we may suppose the numbers a and b, which express the ratio which is assumed between the weight of the highest layer of the body and that of the lowest (the two layers being supposed equal in volume and density), it is possible to express in numbers the ratio of the entire volume to that occupied by the pores as $\sqrt[n]{a}$ to $\sqrt[n]{b}$. Such a ratio may be obtained by experiments with several sorts of tissues, as, for example, by means which Newton indicates in his Optics (Book II, Part III, Prop. 8), the number of the orders of pores being the excess of the logarithm of $\sqrt[n]{a}$ over that of $\sqrt[n]{a}\ \ \sqrt[n]{b}$ divided by the logarithm of two.

[3] The movement of the atoms is so rapid, according to Epicurus (in his letter to Herodotus), that they traverse the greatest imaginable spaces in a time inconceivably short.

XXI.

A second difficulty which would have embarrassed the more scrupulous atomists, is that the mutual collision of the atoms would retard their motions repeatedly, and diminish, consequently, the gravitational action. Any such effect, nevertheless, has hitherto been imperceptible. Now, it would be useless to offer in explanation that the sum of the motions would remain the same, since this is only true when the word sum is used in the sense of geometers, who comprehend by it the difference of contraries. Such a definition is readily seen to offer no assistance to the atomist in the case of equality of contrary movements. For the algebraic sum of the motions of the atoms is zero before as after the collision; but before the collision they were capable of effects of which they are incapable afterwards.

XXII.

It is apparent that such mutual encounters would be the more rare the smaller the atoms were supposed to be compared with the intervals between them. These intervals can not, however, be assumed very great since gravitation manifests no sensible interruption even in places and times the most adjacent; so that the only conceivable recourse to render the encounter of the gravitational atoms sufficiently rare is to suppose them extremely small. Happily this device is completely sufficient. Conceive two balls whose centers trace given courses in different planes. In order that they may never meet it suffices to diminish the sum of their semidiameters till it becomes less than the least distance between their paths.

But since, with diminishing size, the atoms would be less efficient to produce gravitation, the intensity of which is fixed by phenomena,[1] it is necessary to see if their effectiveness may be maintained by some other properties. I see no recourse of this nature except in the increase of individual density or of velocity. These two recourses appear very natural, and are at the same time the more satisfactory because they were (very probably) in accord with the spirit of the atomists of whom I speak, and would probably have sufficed to close the mouths of their adversaries.

XXIII.

Third difficulty: Each celestial body perpetually finds atoms in its path which it necessarily displaces in passing onward. This can not occur without the atoms communicating to the body a part of their motion, and in consequence causing its retardation. Exclusive of all other elements except the mass displaced, this retardation is propor-

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[1] A little metaphysical consideration suffices to dispose of this instance; but, as will be seen in a moment, I am able to supplement it by two separate physical conceptions.

tional to the density of the medium made up of these atoms and their interstices. Now, the gravitation of the body (exclusive of all other elements than this atomic mass) is proportional to this same mean density. How, then, can it be that the retardation is imperceptible while the gravitation is so sensible? The objection is rendered the more forcible when we consider that the retardation of a revolving body is brought about by all the atoms which it meets in its orbit, while its gravitation is produced only by those which at any one position in its orbit are directed toward the central body.

XXIV.

Reply: Other things being equal, the force of gravitation, being produced by the single stream of atoms deprived of antagonists, is proportional to the square of the velocity of the atoms (by a proposition demonstrated generally), while the retardation above spoken of, being caused by the stream opposing the planet in its motion, is proportional to the product of this velocity of the atoms by that of the revolving body (as we shall prove directly). Consequently (things being equal) the gravitation is to the retardation as the velocity of the atoms is to that of the revolving body.

Now, it is not hard to believe that the velocity of the atoms is greater than that of the revolving body; and, indeed, all that we have heretofore said would lead to the presumption that it is incomparably greater. Hence the system of thin-sown atoms moving in every direction agrees very well with a condition of gravitation incomparably greater than the retardation, and it agrees still, despite the consideration which fortifies the difficulty which we are considering, since a velocity has always been assigned to the atoms greater than would have been necessary to obviate this latter difficulty alone.

Remark: I have said that the retardation of a great body caused by the opposing stream of atoms moving much more rapidly than the body itself would be proportional to the product of the velocity of the atoms by that of the great body. I shall first demonstrate this proposition with respect to the couple of opposed streams parallel to the direction of the great body, and in so doing I shall have proved it for the case of opposing streams oblique to this direction, since their motions may be decomposed in two directions, the one parallel and the other perpendicular to the direction of the body, of which the first is nearly always much greater than the motion of the body, and of which the second produces no effect.

Demonstration: The total retardation of the body is the excess of the simple retardation it experiences from the stream which it encounters over the simple acceleration which it experiences on the part of the stream which pursues it. Now, these simple factors are proportional to the squares of velocities, which are respectively the sum and difference of the absolute velocity of the atoms and the absolute velocity of the body. Consequently, the resultant retardation is proportional to the excess of the square of the sum over the square of the difference, which (by the eighth proposition of the second book of the Elements of Euclid) is four times the product of the absolute velocities in question.

XXV.

To the three difficulties above mentioned may be reduced all those which are plausible, since there can be no other changes in the motions of a heavy body, or in the motions of the gravitational fluid, or in their constitution, except those which proceed from some opposition or interposition, either on the part of the particles of the heavy body, which hinder the atoms composing the fluid from reaching their destination, or from particles of the fluid itself, the one opposing the other, or, finally, from the effect of the latter on the path of the heavy body. The solutions of all these difficulties depend either on the permeability of the heavy body or the subtlety and rapidity of the gravitational atoms—properties to none of which we are obliged to assign two opposing limits.

This last expression signifies that while several considerations may unite to augment the intensity of such or such property, yet no consideration requires a diminution in the intensity of the same property, and that reciprocally no considerations tend to limit the diminutiveness of properties of which certain other considerations limit more and more the magnitude. There are no conditions which give opposing indications, and which therefore obstruct the choice of remedies. This assertion would be tedious to establish, but very few readers will contest its correctness.

XXVI.

While we speak of alterations and remedies it is for me to conform to the irregularity of our ordinary progress in research. Truth never permits us to discover her at first seeking, with all her following train of verities, but we proceed gradually in discovery by tedious gropings and corrections. To this procedure a writer ought also in some measure to conform, in the exposition of truths which he has finally discovered, when the greatness or smallness of the objects discussed transcends that of the majority of those objects with which we are familiar, and when he believes that his reader will not at first be disposed to countenance suppositions so excessive, but only in a measure as he shall have shown him their necessity. For the reader will have had no perspective to apply to this immensity or that diminutiveness if it has been assumed at the start in sufficient measure to satisfy all phenomena.

The author might with equal justice assume at the start a magnitude or diminutiveness sufficient for the purpose, since in explaining the phenomena the physicist takes the place (so far as he may) of the Creator—a being who, having determined precisely in advance all the consequences of the different intensities which might be given to such or such properties, has chosen in each case that intensity most proper to attain the desired result and has precisely determined the consequences without any preliminary trial.

XXVII.

All other conceivable objections are founded on certain regularities or irregularities of detail which have not been minutely set forth, but gratuitously assumed, and which, in consequence, ought not seriously to be taken into account. Or, in the second place, such objections may be founded on the tenets of some metaphysical sect. Before responding to such objections I pray these metaphysicists to first agree among themselves. Or, finally, they address themselves to the imagination rather than to the understanding. Thus some may be shocked at what in this system is extreme, strange, or extraordinary—as if it was after our gross and limited measures that the subtlety and grandeur of Nature must be evaluated! As if a confused repugnance sufficed to condemn a theory which depends neither on taste nor sentiment! Or as if one ought to follow servilely the beaten track, even in researches where no success has ever come to those who have followed it!

XXVIII.

If one is satisfied with the exact agreement of this system with physical astronomy and with terrestrial phenomena, he ought not to distrust it, as if this apparent conformity were the effect of the artfulness with which I have adjusted matters or as if other systems also might be rectified so as to agree throughout with the phenomena should a hand more skillful take the same pains to accommodate them to each other.

I have not added to the atoms sung by Lucretius any feature directed solely toward the explanation of the great laws discovered by the Moderns. But, on the contrary, I have merely divested the motion of these atoms of an arbitrary feature (the nearly perfect parallelism) by which Epicurus had disfigured the unrestricted motion assumed by Democritus. That was a motion so simple that it would appear as if its inventor had proposed it with no other end but the most absolute simplicity, unconcerned that it might in no way explain real phenomena, but rather, perhaps, contradict them; so that it is impossible that any system can equal this in simplicity.

I would even have had no need to advise myself of this correction, in reading the poem of Lucretius, if I had been instructed beforehand in the system of Leucippus and Democritus as I was long after this reading.

Finally, the explanations which I have offered ought not to be regarded as in any respect modifications of this system of atoms, for it would be impossible not to fall upon these explanations in seeking to follow out the necessary consequences of this system.

XXIX.

I did not take undue credit to myself when as a child I rectified the system taught by Lucretius and drew from it immediately its most important consequences, for this was extremely easy or rather entirely natural. Besides, I knew but little more the value and solidity of my little views than the child ordinarily knows the wit or sense which we find in its repartees and sallies. Indeed, the extremely simple idea of trying to explain the principal natural phenomena by the aid of a subtle fluid vigorously agitated in every direction has come to many writers who have before presented it in a vague and ill-assured fashion, not to mention that there has been without doubt a still greater number who have not even deigned to communicate at all. I am well convinced that since the law governing the intensity of universal gravitation is similar to that for light, the thought will have occurred to many physicists that an ethereal substance moving in rectilinear paths may be the cause of gravitation, and that they may have applied to it whatever of skill in the mathematics they have possessed.

XXX.

But we may say, How is it that none of these physicists have pushed these consequences to their conclusion and communicated the research? Doubtless because the most of them having no clear view of this chaos (of which the first glance is, I admit, frightful) they have not known how to disentangle it and subject it to their calculations. Or not having firmly grasped the principles of the theory, they have allowed themselves to be seduced by specious sophisms, by which men have pretended to refute in advance all imaginable explanations of gravitation. Or they will have had the foible of bowing to the authority of great names, when it is alleged (whether justly or falsely) that they have pronounced upon the impossibility of this or upon the uselessness of that branch of knowledge. Or they have lacked sufficient love of truth or courage of their convictions to abandon easy pleasures and exterior advantages in order to devote themselves simply to researches at the time difficult and little welcome. Or, finally, they have failed to become impressed with the strength and fecundity of this beautiful system so distinctly as to lead them, in their enthusiasm, to sacrifice to it their other views and projects.

APPENDIX.

Constitutions which I assign to heavy bodies and to the gravitational fluid; followed by a mathematical conception and some remarks to fix the ideas of geometers who desire to follow out for themselves the consequences of this mechanism, and who may desire first to know precisely what are the hypotheses from which I claim all the phenomena to follow necessarily.

CONSTITUTION OF HEAVY BODIES.

First. Their indivisible particles are cages; for example, hollow cubes or octohedra. (They are, in other words, skeletons of solids of which there is nothing material except the edges.)

Second. The diameters of the bars of these cages, even if supposed increased by the diameter of the gravitational corpuscles (as they must be in order to conveniently evaluate the portion of the atoms intercepted), are so small, relative to the distances between the parallel bars of the same cage, that all the particles included in the terrestrial globe intercept not the ten-thousandth part of the corpuscles which present themselves to traverse it.

Third. These diameters are all equal, or if they are unequal their inequalities sensibly compensate each other. If, for instance, in the smallest portions of matter separately ponderable (which, it has been stated, may weigh one thirty-second part of a grain) the mean diameter of the bars of the one portion does not differ a tenth part from the mean diameter of the bars of the other, then it would follow that in the greatest ponderable masses the mean diameters do not differ by a ten-thousandth part, for every such great ponderable mass is composed of so large a number of indivisible particles that simple chance suffices to almost perfectly effect a compensation of diameters.

CONSTITUTION OF GRAVITATIONAL CORPUSCLES.

First. Conformably to the second of the preceding suppositions, the diameter of the gravitational corpuscle added even to that of the bars of the indivisible particles is so small relatively to the mutual distance of the parallel bars of a single cage that the weight of celestial bodies does not sensibly vary from the ratio between their masses.

Second. The gravitational corpuscles are isolated, so that their progressive movements are necessarily rectilinear.

Third. They are so thinly scattered—that is to say, their diameters are so small relative to their mutual mean distance—that there are no more than a few hundreds which encounter one another in the course of a thousand years. Hence the uniformity of their movements is never sensibly disturbed.

Fourth. They move in several thousand of thousands of different directions, even counting as one all those which are parallel to the same line. The distribution of these directions may be conceived as follows: First, imagine all the points conceived to lie in different directions strewn upon a sphere as uniformly as is possible, and consequently separated from one another by less than a second of arc; then imagine a corpuscular path radiating from each of these points.

Fifth. Parallel to each of these directions there moves a stream or torrent of corpuscles. Now, in order to give it no more than the necessary size, the transverse section of this current has the same contour as the orthogonal projection of the visible universe upon the plane of this section.

Sixth. The different parts of a single current are sensibly of equal density, either where contemporary portions of sensible magnitude or successive portions occupying sensible times in traversing a given surface are compared. The densities of different currents are also equal.

Seventh. The mean velocity determined in the same manner as the mean density is also sensibly constant.

Eighth. This velocity is several thousand times as great, relative to the velocities of the planets, as is the gravitation of the planets toward the sun relative to the greatest resistances which secular observations permit us to suppose they experience. For example, several hundred times greater relative to the velocity of the earth than the gravitation of the earth toward the sun multiplied by the number of times the firmament would contain the disc of the sun is greater than the greatest resistance which the secular differences in the length of the year permit us to suppose the earth experiences from celestial matter.

CONCEPT, WHICH FACILITATES THE APPLICATION OF MATHEMATICS TO DETERMINE THE MUTUAL INFLUENCE OF THE HEAVY BODIES AND THE CORPUSCLES.

First. Decompose all heavy bodies into equal masses so small as to allow them to be treated without sensible error as attractive particles are treated in those theories of gravitation in which no hypothesis is made as to its cause. In such a small mass the effects of unequal distance and position of its particles relative to those of the mass which is conceived to attract it, and to be attracted by it, may be neglected. Such masses will have a diameter no more than one one-hundred-thousandth as great as the mutual distance of the two masses under examination. Thus the apparent semidiameter of one as viewed from the other does not exceed one second.

Second. For the surfaces of this mass, accessible but impermeable to the gravitational fluid, substitute a single spherical surface equal to their sum.

Third. Decompose these first surfaces into facets sufficiently small to be treated as planes without sensible error.

Fourth. Transport all these facets to the spherical surface above mentioned. Each one of the facets should in this transformation occupy that point of the spherical surface at which the tangent plane is parallel to the original position of the facet.

REMARKS.

First. It is not necessary to be very expert to deduce upon these suppositions all the laws of gravitation, both terrestrial and universal (and consequently those of Kepler and some others), with as much of precision and more as the phenomena themselves furnish, for these laws are the inevitable consequences of the constitutions I have supposed.

Second. Although I here present these constitutions crudely and without proof, as if they were gratuitous hypotheses and adventurous fictions, the fair-minded reader will perfectly comprehend that I have at hand some presumptions, at least, in their favor (independent of the perfect accord with all the phenomena), but which I withhold as too extended for development in this place. These suppositions may then be regarded as theorems published without demonstration.

Third. Their number is likely to inspire some opposition at first glance; but the attentive mind will not fail to see that they are but details into which I have wished to enter because of the novelty of this doctrine, and that they will be readily understood when it shall have become sufficiently well known that its students may attend under favorable circumstances to the details. If the authors who have written upon hydrodynamics, aeronautics, or optics had had readers who doubted the existence of water, air, and light, and who consequently indulged no tacit supposition upon equalities or compensations of which no express mention was made, they, too, would be obliged to add a great number of explanations to their definitions which instructed or indulgent readers might well dispense with. We do not accept of hints, and sano sensu, except for propositions which are familiar and in whose favor there is a predisposition.

THE EXTREME INFRA-RED RADIATIONS.[1]

By C. E. GUILLAUME.

If we compare our present knowledge of the spectrum with what was known even as recently as ten years ago, we can but marvel at the progress that has been made in that brief period. In 1888 the ultra-violet spectrum had been investigated by M. Cornu, but only as far as the point at which the air totally absorbs the rays. In the infra-red, the region actually measured did not extend below 2 or 3 microns, although Langley had explored for some distance beyond.[2] Electrical waves were then making their first appearance and scientists were far from being in accord as to their true nature, few then admitting them to be identical in fundamental character with light.

To-day the spectrum has been continued a whole octave toward the shorter wave lengths by means of experiments conducted in vacuo. The X rays and the uranium rays, or secondary rays derived from X rays, have still further extended the ultraviolet spectrum through regions not yet measured. Electrical oscillations, which from their various properties have been shown to belong in the octaves below those of light, have now been produced with wave lengths of about 3 millimeters; while the infra-red proper—that is, the direct continuation of the spectrum beyond the visible ending in the red—has extended itself more and more, bridging over the unknown region toward the electrical waves.

Progress in this infra-red region, after having been singularly slow for several years, has recently become very rapid. Extremely meritorious researches have added largely to the older work, and have led to results of the highest interest in the knowledge of the vibratory motions of the ether, which we still continue to call light, although, for the physicist, those radiations which are visible form but a minute portion of the whole.

Our readers will recall that the infra-red radiations are revealed to us only through their transformation into heat at the surface of some suitable receiver. This is often a thin strip of platinum or iron or

[1] Translated from La Nature, No. 1325, pp. 332–334, October, 1898.

[2] Translator's note: This statement is slightly in error. The wave-length measurements of Langley in 1886 extended as far as 5.3 microns.

nickel, blackened, and introduced as a resistance to form part of an electric circuit; but sometimes it is a very minute thermopile caused to affect a highly sensitive galvanometer.

The production of extreme infra-red rays is very simple, as all bodies whatsoever emit them constantly. If, however, an opaque body is at the same temperature as the receiver, the radiations which it sends out are imperceptible, because the two bodies exchange equal quantities of energy.

The hotter a body, the more it emits radiations of all kinds. But the difficulty is to isolate separate bundles of these rays from their neighbors, so as to deal with rays of approximately the same wave length. Prisms of most substances are useless for these long wave lengths, as they generally absorb the rays totally, just as lampblack does in the visible spectrum, while the grating, as is well known, superposes many orders of spectra having wave lengths which are multiples of each other.

A very ingenious device originated by the American physicist, Nichols, has been of very great service here. In studying the nature of the radiations reflected by quartz, Nichols found that the fraction reflected was very slight through the greater part of the spectrum, but increased very greatly at certain regions in the infra-red, where, indeed, this substance seemed to have a really metallic reflection. These regions of nearly total reflection were tolerably narrow and well marked. At each successive reflection from quartz surfaces all the radiations become more and more enfeebled by absorption in the quartz, with the exception of those whose wave lengths correspond to such regions of metallic reflection. These bands thus become relatively stronger and stronger at each reflection till, after four or five reflections, they alone remain perceptible.

By interposing a grating in the path of the beam the wave lengths under investigation may be determined. The apparatus for this purpose is, however, quite different from that employed in the visible spectrum. For example, the grating is composed of metallic wires, each one or two tenths of a millimeter in diameter, and the slit through which the radiations pass may be as much as a centimeter wide without making the spectrum too impure. It is not necessary that the reflecting surfaces shall be polished with that degree of accuracy and finish required in the visible spectrum. For the proportion of radiations diffusely reflected by a surface depends not only on the size of the grains of the surface, but on the wave lengths of the radiations reflected. Infra-red measurements now frequently deal with radiations of a wave length a hundred times as great as that of green light, and thus the optical surfaces may be much inferior to those which would be required for work in the visible spectrum.

Quartz is not alone in possessing this property of selective reflection of which we have been speaking. A great number of other crystalline substances have narrow bands of metallic reflection at various points in the spectrum, and they can be utilized in the same way to produce pure pencils of rays. With quartz, the principal of these bands are situated at wave lengths of 8μ and 21μ, while, according to Rubens and Aschkinass, the rays reflected most completely by rock salt and by sylvine have wave lengths respectively of 51μ and 61μ. This last wave length is exactly one hundred times as great as that of the orange in the visible spectrum.

The diagram (fig. 1) represents the disposition of apparatus in the investigation of Rubens and Aschkinass. At L is the lamp sending out its radiations to the mirror M_1 by which the beam is reflected to M_2. Between these mirrors is placed the grating R. After leaving M_2 the beam suffers five reflections at the surfaces S, proceeds then to the mirror M_3, and finally falls upon the receiving surface placed in

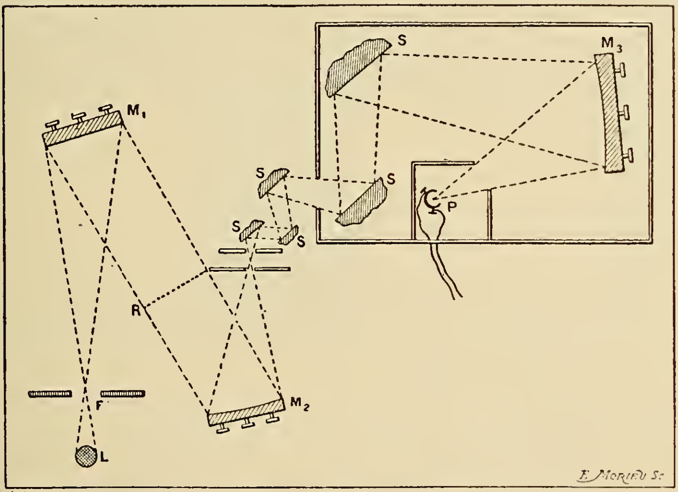

FIG. 1.—Diagram showing arrangement of apparatus for studying infra-red spectrum.

the small reflecting chamber P. By this latter device the rays not absorbed at first contact with the receiving surface are reflected back upon it by the walls of the chamber, and thus serve more effectively to warm it. A series of screens is so arranged as to exclude from this chamber all stray light.

However interesting we may consider the fact of the existence of these bands of selective reflection, their chief value lies in their application to the purposes of investigation. No procedure known prior to their discovery could be used to separate homogeneous pencils of rays of these great wave lengths in sufficient intensity for an examination of their properties.

One of the first studies which have been made with regard to these rays is the transparency of various substances to them. It has been shown that the rays separated by the use of quartz traverse rock salt quite readily, and still more freely the precipitated chloride of silver. The radiations peculiar to rock salt are completely untransmissible to rock salt and chloride of silver, as well as to glass, gypsum, and fluorspar. Paraffin in layers of 1 millimeter thickness transmits nearly half of these radiations of rock salt, and a comparison with the radiation peculiar to sylvine shows paraffin becoming more and more transparent as we proceed further in the infra-red. The same is true of the transmitting power of quartz, fluorite, and gutta-percha.

A sheet of isinglass transmits nearly two-thirds of each of these kinds of radiation. The authors therefore employed this substance to form a cell in which to put various liquids whose transparency was to be examined. Carbon-bisulphide and benzine were found to be very transparent, petroleum somewhat less so, and toluene and xylene still more opaque. Thus the fractions of the rays separated by rock salt which traversed 1 millimeter thickness of carbon-bisulphide and xylene were 98 per cent and 16 per cent, respectively. The case of olive oil is

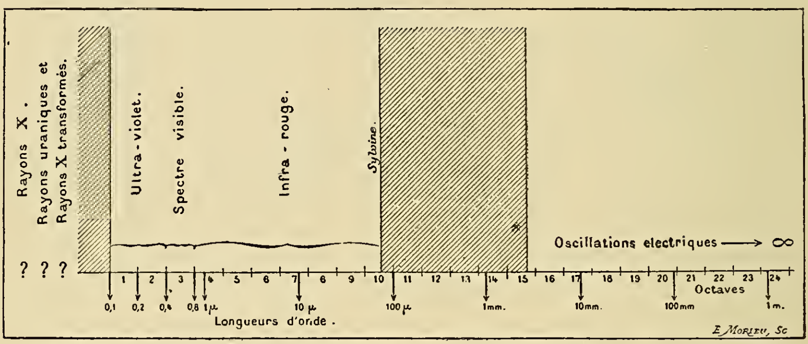

FIG. 2.—The spectrum divided into octaves. The shaded parts have not been exposed.

singular. While completely opaque to rays of the wave length 51μ, a layer of it 1 millimeter thick transmits 20 per cent of those at 61μ. Water, alcohol, and ether are completely opaque to both these kinds of radiations, and while carbonic-acid vapor absorbs them but slightly, water vapor absorbs them almost completely.

These observations show us anew how marked are the differences in the properties of ether waves of slightly different periods of oscillation. It appears, according to modern theories, that if a substance is transparent at one region of the spectrum, it is necessarily opaque at some other. Indeed, if we except the case of the metals, we must search for substances transparent in the infra-red among those opaque to visible radiations.

Nothing more clearly indicates the great generalization in the notion of light that has taken place in the last decade than the simple statistics of comparison between the extent of spectrum as now known and the narrow visible stretch included between the violet and the red.

This comparison becomes clearer in a graphic representation, which can be made by either of the two following methods: The wave lengths may be plotted as abscissæ upon a simple arithmetical scale, or for them may be substituted their logarithms, so as to make a geometrical scale in which each octave of light occupies an equal space in counterpart to the keyboard of a piano. The second method is the more rational, inasmuch as it gives to each part of the spectrum a space more in proportion to its importance.

The diagram (fig. 2) has been prepared in conformity with the second scheme.[1]

The light spaces in the diagram correspond to the spectrum now known, while the shaded portions represent spectral regions not yet explored. The light portion grows continually, and there now remains unknown only a small region to remind us of the part formerly in obscurity.

[1] The octaves in the figure are numbered arbitrarily and arranged in the opposite direction to the musical octaves on a piano keyboard. That is, the octaves of radiations of more rapid vibration, which may be compared to higher musical pitches, are upon the left. It would be useful to adopt some fixed numbering for the octaves of radiation.

THE CHEMISTRY OF THE STARS.[1]

By Sir NORMAN LOCKYER.

When, on returning from India, I found that you had during my absence done me the honor of unanimously electing me your president, I began to cast about for a subject on which to address you. Curiously enough, shortly afterwards an official inquiry compelled me to make myself acquainted with the early doings of the Royal Commission of the Exhibition of 1851, on which I have lately been elected to serve, and in my reading I found a full account of the establishment of your institute; of the laying of the foundation stone by the late Prince Consort in 1855, and of his memorable speech on that occasion. Here, I thought, was my subject; and when I heard that the admirable work done by this and other local institutions had determined the inhabitants of this important city and neighborhood to crown the edifice by the foundation of a university, I thought the matter settled.

This idea, however, was nipped in the bud by a letter which informed me that the hope had been expressed that I should refer to some branch of astronomical work. I yielded at once, and because I felt that I might thus be able to show cause why the making of knowledge should occupy a large place in your new university, and thus distinguish it from other universities more or less decadent.

The importance of practical work, the educational value of the seeking after truth by experiment and observation on the part of even young students, are now generally recognized. That battle has been fought and won. But there is a tendency in the official direction of seats of learning to consider what is known to be useful, because it is used, in the first place. The fact that the unknown, that is the unstudied, is the mine from which all scientific knowledge with its million applications has been won is too often forgotten.

Bacon, who was the first to point out the importance of experiment in the physical sciences, and who predicted the applications to which I have referred, warns us that "lucifera experimenta non fructifera quaerenda;" and surely we should highly prize those results which enlarge

[1] An inaugural address delivered at the Birmingham and Midland Institute on October 26, 1898, by Sir Norman Lockyer, K. C. B., F. R. S., president. Printed in Nature, November 10, 1898. Vol. 59, No. 1515.

the domain of human thought and help us to understand the mechanism of the wonderful universe in which our lot is cast, as well as those which add to the comfort and the convenience of our lives.

It would be also easy to show by many instances how researches, considered ideally useless at the time they were made, have been the origin of the most tremendous applications. One instance suffices. Faraday's trifling with wires and magnets has already landed us in one of the greatest revolutions which civilization has witnessed; and where the triumphs of electrical science will stop no man can say.

This is a case in which the useless has been rapidly sublimed into utility so far as our material wants are concerned.

I propose to bring to your notice another "useless" observation suggesting a line of inquiry which I believe sooner or later is destined profoundly to influence human thought along many lines.

Fraunhofer at the beginning of this century examined sunlight and starlight through a prism. He found that the light received from the sun differed from that of the stars. So useless did his work appear that we had to wait for half a century till any considerable advance was made. It was found at last that the strange "lines" seen and named by Fraunhofer were precious indications of the chemical substances present in worlds immeasurably remote. We had, after half a century's neglect, the foundation of solar and stellar chemistry, an advance in knowledge equaling any other in its importance.

In dealing with my subject I shall first refer to the work which has been done in more recent years with regard to this chemical conditioning of the atmospheres of stars, and afterwards very briefly show how this work carries us into still other new and wider fields of thought.

The first important matter which lies on the surface of such a general inquiry as this is that if we deal with the chemical elements as judged by the lines in their spectra we know for certain of the existence of oxygen, of nitrogen, of argon, representing one class of gases, in no celestial body whatever; whereas, representing other gases, we have a tremendous demonstration of the existence of all the known lines of hydrogen and helium.

We see, then, that the celestial sorting out of gases is quite different from the terrestial one.

Taking the substances classed by the chemist as nonmetals, we find carbon and silicium—I prefer, on account of its stellar behavior, to call it silicium, though it is old fashioned—present in celestial phenomena. We have evidence of this in the fact that we have a considerable development of carbon in some stars and an indication of silicium in others. But these are the only nonmetals observed. Now, with regard to the metallic substances which we find, we deal chiefly with calcium, strontium, iron, and magnesium. Others are not absolutely absent, but their percentage quantity is so small that they are negligible in a general statement.

Now do these chemical elements exist indiscriminately in all the celestial bodies, so that practically, from a chemical point of view, the bodies appear to us of similar chemical constitution? No; it is not so.

From the spectra of those stars which resemble the sun, in that they consist of an interior nucleus surrounded by an atmosphere which absorbs the light of the nucleus, and which, therefore, we study by means of this absorption, it is to be gathered that the atmospheres of some stars are chiefly gaseous—i. e., consisting of elements we recognize as gases here—of others chiefly metallic, of others again mainly composed of carbon or compounds of carbon.

Here, then, we have spectroscopically revealed the fact that there is considerable variation in the chemical constituents which build up the stellar atmospheres.

This, though a general, is still an isolated statement. Can we connect it with another? One of the laws formulated by Kirchhoff in the infancy of spectroscopic inquiry has to do with the kind of radiation given out by bodies at different temperatures. A poker placed in a fire first becomes red and, as it gets hotter, white hot. Examined in a spectroscope, we find that the red condition comes from the absence of blue light; that the white condition comes from the gradual addition of blue as the temperature increases.

The law affirms that the hotter a mass of matter is the farther its spectrum extends into the ultraviolet.

Hence the hotter a star is the farther does its complete or continuous spectrum lengthen out toward the ultraviolet and the less is it absorbed by cooler vapors in its atmosphere.

Now, to deal with three of the main groups of stars, we find the following very general result:

Gaseous stars	Longest spectrum.
Metallic stars	Medium spectrum.
Carbon stars	Shortest spectrum.

We have now associated two different series of phenomena, and we are enabled to make the following statement:

Gaseous stars	Highest temperature.
Metallic stars	Medium temperature.
Carbon stars	Lowest temperature.

Hence the differences in apparent chemical constitutions are associated with differences of temperature.

Can we associate with the two to which I have already called attention still a third class of facts? Laboratory work enables us to do this. When I began my inquiries the idea was, one gas or vapor one spectrum. We now know that this is not true; the systems of bright lines given out by radiating substances change with the temperature.

We can get the spectrum of a well-known compound substance—say carbonic oxide; it is one special to the compound; we increase the temperature so as to break up the compound, and we then get the spectra of its constituents, carbon and oxygen.

But the important thing in the present connection is that the spectra of the chemical elements behave exactly in the same way as the spectra of known compounds do when we employ temperatures far higher than those which break up the compounds; and indeed in some cases the changes are more marked. For brevity I will take for purposes of illustration three substances, and deal with one increase of temperature only, a considerable one and obtainable by rendering a substance incandescent, first by a direct current of electricity, as happens in the so-called "arc lamps" employed in electric lighting, and next by the employment of a powerful induction coil and battery of leyden jars. In laboratory parlance we pass thus from the arc to the jar-spark. In the case of magnesium, iron, and calcium, the changes observed on passing from the temperature of the arc to that of the spark have been minutely observed. In each, new lines are added or old ones are intensified at the higher temperature. Such lines have been termed "enhanced lines."

These enhanced lines are not seen alone; outside the region of high temperature in which they are produced, the cooling vapors give us the cool lines. Still we can conceive the enhanced lines to be seen alone at the highest temperature in a space sufficiently shielded from the action of all lower temperatures, but such a shielding is beyond our laboratory expedients.

In watching the appearance of these special enhanced lines in stellar spectra we have a third series of phenomena available, and we find that the results are absolutely in harmony with what has gone before. Thus:

Gaseous stars..Highest temperature..	Strong helium and faint enhanced lines.
Metallic stars..Medium temperature..	Feeble helium and strong enhanced lines. No helium and strong arc lines.
Carbon stars..Lowest temperature...	Faint arc lines.

It is clear now, not only that the spectral changes in stars are associated with, or produced by, changes of temperature, but that the study of the enhanced spark and the arc lines lands us in the possibility of a rigorous stellar thermometry, such lines being more easy to observe than the relative lengths of spectrum.

Accepting this, we can take a long stride forward and, by carefully studying the chemical revelations of the spectrum, classify the stars along a line of temperature. But which line? Were all the stars in popular phraseology created hot? If so, we should simply deal with the running down of temperature, and because all the hottest stars are chemically alike, all cooler stars would be alike. But there are two very distinct groups of coolest stars; and since there are two different kinds of coolest stars, and only one kind of hottest stars, it can not be merely a question either of a running up or a running down of temperature.

Many years of very detailed inquiry have convinced me that all stars save the hottest must be sorted out into two series—those getting hotter and those, like our sun, getting cooler, and that the hottest stage in the history of a star is reached near the middle of its life.

The method of inquiry adopted has been to compare large-scale photographs of the spectra of the different stars taken by my assistants at South Kensington; the complete harmony of the results obtained along various lines of other work carries conviction with it.

We find ourselves here in the presence of minute details exhibiting the workings of a chemical law, associated distinctly with temperature; and more than this, we are also in the presence of high-temperature furnaces, entirely shielded by their vastness from the presence of those distracting phenomena which we are never free from in the most perfect conditions of experiment we can get here.

What, then, is the chemical law? It is this: In the very hottest stars we deal with the gases hydrogen, helium, and doubtless others still unknown, almost exclusively. At the next lowest temperatures we find these gases being replaced by metals in the state in which they are observed in our laboratories when the most powerful jar-spark is employed. At a lower temperature still the gases almost disappear entirely, and the metals exist in the state produced by the electric arc. Certain typical stars showing these chemical changes may be arranged as follows:

Stars getting hotter.	Hottest stars.	Stars cooling.
	Bellatrix	
ζ Tauri		β Persei
Rigel		γ Lyra
α Cygni		Castor
γ Cygni		Procyon
α Orionis		Arcturus and Sun.

This, then, is the result of our first inquiry into the existence of the various chemical elements in the atmospheres of stars generally. We get a great diversity, and we know that this diversity accompanies changes of temperature. We have also found that the sun, which we independently know to be a cooling star, and Arcturus are identical chemically.

We have now dealt with the presence of the various chemical elements generally in the atmospheres of stars. The next point we have to consider is, whether the absorption which the spectrum indicates for us takes place from top to bottom of the atmosphere or only in certain levels.

In many of these stars the atmosphere may be millions of miles high. In each the chemical substances in the hottest and coldest portions may be vastly different. The region, therefore, in which this absorption takes place, which spectroscopically enables us to discriminate star from star, must be accurately known before we can obtain the greatest amount of information from our inquiries.

Our next duty then, clearly, is to study the sun—a star so near us that we can examine the different parts of its atmosphere, which we can not do in the case of the more distant stars. By doing this we may secure facts which will enable us to ascertain in what parts of the atmosphere the absorption takes place which produces the various phenomena on which the chemical classification has been based.

It is obvious that the general spectrum of the sun, like that of stars generally, is built up of all the absorptions which can make themselves felt in every layer of its atmosphere from bottom to top; that is, from the photosphere to the outermost part of the corona. Let me remind you that this spectrum is changeless from year to year.

Now, sun-spots are disturbances produced in the photosphere; and the chromosphere, with its disturbances, called prominences, lies directly above it. Here, then, we are dealing with the lowest part of the sun's atmosphere. We find first of all that, in opposition to the changeless general spectrum, great changes occur with the sun-spot period, both in the spots and chromosphere.

The spot spectrum is indicated, as was found in 1866, by the widening of certain lines; the chromospheric spectrum, as was found in 1868, by the appearance at the sun's limb of certain bright lines. In both cases the lines affected, seen at any one time, are relatively few in number.

In the spot spectrum, at a sun-spot minimum, we find iron lines chiefly affected; at a maximum they are chiefly of unknown or unfamiliar origin. At the present moment the affected lines are those recorded in the spectra of vanadium and scandium, with others never seen in a laboratory. That we are here far away from terrestrial chemical conditions is evidenced by the fact that there is not a gram of scandium available for laboratory use in the world at the present time.

Then we have the spectrum of the prominences and the chromosphere. That spectrum we are enabled to observe every day when the sun shines as conveniently as we can observe that of sun spots. The chromosphere is full of marvels. At first, when our knowledge of spectra was very much more restricted than now, almost all the lines observed were unknown. In 1868 I saw a line in the yellow, which I found behaved very much like hydrogen, though I could prove that it was not due to hydrogen; for laboratory use the substance which gave rise to it I called helium. Next year I saw a line in the green at 1474 of Kirchhoff's scale. That was an unknown line, but in some subsequent researches I traced it to iron. From that day to this we have observed a large number of lines. They have gradually been dragged out from the region of the unknown, and many are now recognized as enhanced lines, to which I have already called attention as appearing in the spectra of metals at a very high temperature.

But useful as the method of observing the chromosphere without an eclipse, which enables us

"... to feel from world to world,"

as Tennyson has put it, has proved, we want an eclipse to see it face to face.

A tremendous flood of light has been thrown upon it by the use of large instruments constructed on a plan devised by Respighi and myself in 1871. These give us an image of the chromosphere painted in each one of its radiations, so that the exact locus of each chemical layer is revealed. One of the instruments employed during the Indian eclipse of this year is that used in photographing the spectra of stars, so that it is now easy to place photographs of the spectra of the chromosphere obtained during a total eclipse and of the various stars side by side.

I have already pointed out that the chemical classification indicated that the stars next above the sun in temperature are represented by γ Cygni and Procyon, one on the ascending, the other on the descending branch of the temperature curve.

Studying the spectra photographed during the eclipse of this year we see that practically the lower part of the sun's atmosphere, if present by itself, would give us the lines which specialize the spectra of γ Cygni or Procyon.

I recognize in this result a veritable Rosetta stone, which will enable us to read the celestial hieroglyphics presented to us in stellar spectra, and help us to study the spectra and to get at results much more distinctly and certainly than ever before.

One of the most important conclusions we draw from the Indian eclipse is that, for some reason or other, the lowest, hottest part of the sun's atmosphere does not write its record among the lines which build up the general spectrum so effectively as does a higher one.

There was another point especially important on which we hoped for information, and that was this: Up to the employment of the prismatic camera insufficient attention had been directed to the fact that in observations made by an ordinary spectroscope no true measure of the height to which the vapors or gases extended above the sun could be obtained; early observations, in fact, showed the existence of glare between the observer and the dark moon; hence it must exist between us and the sun's surroundings.

The prismatic camera gets rid of the effects of this glare, and its results indicate that the effective absorbing layer—that, namely, which gives rise to the Fraunhofer lines—is much more restricted in thickness than was to be gathered from the early observations.

We are justified in extending these general conclusions to all the stars that shine in the heavens.

So much then, in brief, for solar teachings in relation to the record of the absorption of the lower parts of stellar atmospheres.

Let us next turn to the higher portions of the solar surroundings, to see if we can get any effective help from them.

In this matter we are dependent absolutely upon eclipses, and I shall fulfill my task very badly if I do not show you that the phenomena then observable when the so-called corona is visible, full of awe and grandeur to all, are also full of precious teaching to the student of science. This also varies like the spots and prominences with the sun-spot period.

It happened that I was the only person that saw both the eclipse of 1871 at the maximum of the sun-spot period and that of 1878 at minimum; the corona of 1871 was as distinct from the corona of 1878 as anything could be. In 1871 we got nothing but bright lines, indicating the presence of gases; namely, hydrogen and another, since provisionally called coronium. In 1878 we got no bright lines at all, so I stated that probably the changes in the chemistry and appearance of the corona would be found to be dependent upon the sun-spot period, and recent work has borne out that suggestion.

I have now specially to refer to the corona as observed and photographed this year in India by means of the prismatic camera, remarking that an important point in the use of the prismatic camera is that it enables us to separate the spectrum of the corona from that of the prominences.

One of the chief results obtained is the determination of the position of several lines of probably more than one new gas, which, so far, have not been recognized as existing on the earth.

Like the lowest hottest layer, for some reason or other, this upper layer does not write its record among the lines which build up the general spectrum.

GENERAL RESULTS REGARDING THE LOCUS OF ABSORPTION IN STELLAR ATMOSPHERES.

We learn from the sun, then, that the absorption which defines the spectrum of a star is the absorption of a middle region, one shielded both from the highest temperature of the lowest reaches of the atmosphere, where most tremendous changes are continually going on and the external region where the temperature must be low, and where the metallic vapors must condense.

If this is true for the sun it must be equally true for Arcturus, which exactly resembles it. I go further than this, and say that in the presence of such definite results as those I have brought before you it is not philosophical to assume that the absorption may take place at the bottom of the atmosphere of one star or at the top of the atmosphere of another. The onus probandi rests upon those who hold such views.

So far I have only dealt in detail with the hotter stars, but I have pointed out that we have two distinct kinds of coolest ones, the evidence of their much lower temperature being the shortness of their spectra.

In one of these groups we deal with absorption alone, as in those already considered; we find an important break in the phenomena observed; helium, hydrogen, and metals have practically disappeared, and we deal with carbon absorption alone.

But the other group of coolest stars presents us with quite new phenomena. We no longer deal with absorption alone, but accompanying it we have radiation, so that the spectra contain both dark lines and bright ones. Now, since such spectra are visible in the case of new stars, the ephemera of the skies, which may be said to exist only for an instant relatively, and when the disturbance which gives rise to their sudden appearance has ceased we find their places occupied by nebulæ, we can not be dealing here with stars like the sun, which has already taken some millions of years to slowly cool, and requires more millions to complete the process into invisibility.

The bright lines seen in the large number of permanent stars which resemble these fleeting ones—new stars, as they are called—are those discerned in the once mysterious nebulæ which, so far from being stars, were supposed not many years ago to represent a special order of created things.

Now the nebulæ differ from stars generally in the fact that in their spectra we have practically to deal with radiation alone; we study them by their bright lines; the conditions which produce the absorption by which we study the chemistry of the hottest stars are absent.

A NEW VIEW OF STARS.

Here, then, we are driven to the perfectly new idea that some of the cooler bodies in the heavens, the temperature of which is increasing and which appear to us as stars, are really disturbed nebulæ.

What, then, is the chemistry of the nebulæ? It is mainly gaseous; the lines of helium and hydrogen and the flutings of carbon, already studied by their absorption in the groups of stars to which I have already referred, are present as bright ones.

The presence of the lines of the metals iron, calcium, and probably magnesium, shows us that we are not dealing with gases merely.

Of the enhanced metallic lines there are none; only the low temperature lines are present, so far as we yet know. The temperature, then, is low, and lowest of all in those nebulæ where carbon flutings are seen almost alone.

A NEW VIEW OF NEBULÆ.

Passing over the old views, among them one that the nebulæ were holes in something dark which enabled us to see something bright beyond, and another that they were composed of a fiery fluid, I may say that not long ago they were supposed to be masses of gases only, existing at a very high temperature.

Now, since gases may glow at a low temperature as well as at a high one, the temperature evidence must depend upon the presence of cool metallic lines and the absence of the enhanced ones.

The nebulæ, then, are relatively cool collections of some of the permanent gases and of some cool metallic vapors, and both gases and metals are precisely those I have referred to as writing their records most visibly in stellar atmospheres.

Now, can we get more information concerning this association of certain gases and metals? In laboratory work it is abundantly recognized that all meteorites (and many minerals) when slightly heated give out permanent gases, and under certain conditions the spectrum of the nebulæ may in this way be closely approximated to. I have not time to labor this point, but I may say that a discussion of all the available observations to my mind demonstrates the truth of the suggestion, made many years ago by Professor Tait before any spectroscopic facts were available, that the nebulæ are masses of meteorites rendered hot by collisions.

Surely human knowledge is all the richer for this indication of the connection between the nebulæ, hitherto the most mysterious bodies in the skies, and the "stones that fall from heaven."

CELESTIAL EVOLUTION.

But this is, after all, only a steppingstone, important though it be. It leads us to a vast generalization. If the nebulæ are thus composed, they are bound to condense to centers, however vast their initial proportions, however irregular the first distribution of the cosmic clouds which compose them. Each pair of meteorites in collision puts us in mental possession of what the final stage must be. We begin with a feeble absorption of metallic vapors round each meteorite in collision; the space between the meteorites is filled with the permanent gases driven out farther afield and having no power to condense. Hence dark metallic and bright gas lines. As time goes on the former must predominate, for the whole swarm of meteorites will then form a gaseous sphere with a strongly heated center, the light of which will be absorbed by the exterior vapor.

The temperature order of the group of stars with bright lines as well as dark ones in their spectra has been traced, and typical stars indicating the chemical changes have been as carefully studied as those in which absorption phenomena are visible alone, so that now there are no breaks in the line connecting the nebulæ with the stars on the verge of extinction.

Here we are brought to another tremendous outcome—that of the evolution of all cosmical bodies from meteorites, the various stages recorded by the spectra being brought about by the various conditions which follow from the conditions.

These are, shortly, that at first collisions produce luminosity among the colliding particles of the swarm, and the permanent gases are given off and fill the interspaces. As condensation goes on, the temperature at the center of condensation always increasing, all the meteorites in time are driven into a state of gas. The meteoritic bombardment practically now ceases for lack of material, and the future history of the mass of gas is that of a cooling body, the violent motions in the atmosphere while condensation was going on now being replaced by a relative calm.

The absorption phenomena in stellar spectra are not identical at the same mean temperature on the ascending and descending sides of the curve, on account of the tremendous difference in the physical conditions.

In a condensing swarm, the center of which is undergoing meteoritic bombardment from all sides, there can not be the equivalent of the solar chromosphere; the whole mass is made up of heterogeneous vapor at different temperatures and moving with different velocities in different regions.

In a condensed swarm, of which we can take the sun as a type, all action produced from without has practically ceased; we get relatively a quiet atmosphere and an orderly assortment of the vapors from top to bottom, disturbed only by the fall of condensed metallic vapors. But still, on the view that the differences in the spectra of the heavenly bodies chiefly represent differences in degree of condensation and temperature, there can be, au fond, no great chemical difference between bodies of increasing and bodies of decreasing temperature. Hence we find at equal mean temperatures on opposite sides of the temperature curve this chemical similarity of the absorbing vapors proved by many points of resemblance in the spectra, especially the identical behavior of the enhanced metallic and cleveite lines.

CELESTIAL DISSOCIATION.

The time you were good enough to put at my disposal is now exhausted, but I can not conclude without stating that I have not yet exhausted all the conceptions of a high order to which Fraunhofer's apparently useless observation has led us.

The work which to my mind has demonstrated the evolution of the cosmos as we know it from swarms of meteorites, has also suggested a chemical evolution equally majestic in its simplicity.

A quarter of a century ago I pointed out that all the facts then available suggested the hypothesis that in the atmospheres of the sun and stars various degrees of "celestial dissociation" were at work, a "dissociation" which prevented the coming together of the finest particles of matter which at the temperature of the earth and at all artificial temperature yet attained here compose the metals, the metalloids and compounds.

On this hypothesis the so-called atoms of the chemist represent not the origins of things, but only early stages of the evolutionary process.

At the present time we have tens of thousands of facts which were not available twenty-five years ago. All these go to the support of the hypothesis, and among them I must indicate the results obtained at the last eclipse, dealing with the atmosphere of the sun in relation to that of the various stars of higher temperature to which I called your attention. In this way we can easily explain the enhanced lines of iron existing practically alone in Alpha Cygni. I have yet to learn any other explanation.

I have nothing to take back, either from what I then said or what I have said since on this subject, and although the view is not yet accepted, I am glad to know that many other lines of work which are now being prosecuted tend to favor it.

I have no hesitation in expressing my conviction that in a not distant future the inorganic evolution to which we have been finally led by following up Fraunhofer's useless experiment will take its natural place side by side with that organic evolution the demonstration of which has been one of the glories of the nineteenth century.

And finally now comes the moral of my address. If I have helped to show that observations having no immediate practical bearing may yet help on the thought of mankind, and that this is a thing worth the doing, let me express a hope that such work shall find no small place in the future University of Birmingham.

THE PERCEPTION OF LIGHT AND COLOR.[1]

By Georges Lechalas

Twenty years ago, while on a railway car, I accidentally made an observation which strongly attracted my attention. Having held one eye closed for a certain time, I reopened it during the passage of the train through a tunnel. The consciousness of a profound inequality in the vision of my two eyes led me to close them alternately, and I thus verified not only that the sensitiveness of the eye previously closed was greater than that of the other, exposed just before to the full light, but also that there was a profound difference in the coloration of the images. While in fact the image corresponding to the latter was quite clearly yellowish, the other was white or even of a violet hue. This violet tint, if real, could be explained by the phenomenon of contrast with the yellow of the other eye; but it nevertheless persisted, notwithstanding the fact that yellow light, thrown by a lamp on objects, appeared white to an eye which had ceased to be adapted to solar light.

This observation naturally leads to the hypothesis that color has only a purely relative value, and that light of every color should appear colorless to an eye which has been in repose. To verify this hypothesis I bandaged both eyes, and at the expiration of ten minutes I opened them again in a room illuminated through a plate of blue gelatin. The blue color was found to be much fainter, but quite distinguishable. Repeating the experiment with a plate of red gelatin, no attenuation of color was observed, although both eyes had been kept in darkness for a still longer time. The hypothesis was thus disproved by experiment. I did not continue the investigation, for which, besides, I was not properly equipped with apparatus. If I had better followed the trend of scientific research I would have known that Dr. Charpentier, professor in the medical faculty at Nancy, had already devoted himself to extremely interesting studies of this class of phenomena, in which he was soon followed by Dr. Parinaud; then the Germans entered the lists, and to-day there exists an extensive scientific literature on the subject. It possibly will not, therefore, be uninteresting to give a résumé of the conclusions thus far deduced from the experimental results obtained.

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[1] Translated from Revue des Questions Scientifiques, Louvain, April, 1899, pp. 476–504.

Let us begin with a study of the psychic phenomena which have been observed—that is to say, the sensations and perceptions; next we will consider the physiological phenomena to which these psychic phenomena appear related, and finally the theories which have been erected on the framework of this ensemble of facts will be briefly reviewed.

I.—PSYCHIC PHENOMENA.

The phenomena which we are about to describe were first discussed in M. Charpentier's publications, as has already been stated, but the results reached by him are of a more complicated character than those of M. Parinaud, whose first contribution on the subject was published in 1881, while that of his rival dates back to 1877. It is as if Regnault's work had preceded that of Mariotte. Without pretending to decide their dispute in regard to priority, let us remark that it is easier to begin by a study of Mariotte, or in the present case of Parinaud. The latter, in a recently published treatise, summarizes the results of his experiments on the adaptation of the retina to obscurity as follows:

1. The increase in the sensitiveness of the retina, which characterizes adaptation to obscurity, varies according to the wave length of the light; it is greater the smaller the wave length. The influence of adaptation which is zero for spectral red becomes considerable for the violet and ultraviolet.
2. This increase of sensitiveness affects only the luminous value of simple light. The color appears brighter and less saturated. Finally, after a sufficient time spent in darkness, the purest spectral colors of feeble intensity are perceived as uncolored light, the red alone excepted.
3. This increase in the sensitiveness is lacking in the fovea.[1] The fovea does not participate in retinal adaptation. The sensation of color not being altered by adaptation in the fovea, luminous impressions are always perceived in that region as colors.[2]

On reading these enunciations one is struck by the very characteristic fact that although white has generally been considered as being essentially a complex color, we see that for luminous excitations received outside the fovea all light, the red excepted, is perceived first as colorless and, for a retina adapted to obscurity, remains strongly diluted in appearance, whatever be its intensity. There are, then, two kinds of sensibility which, according to M. Charpentier, may be distinguished by the terms luminous sensibility (properly so called) and chromatic sensibility[3]. It may be remarked that, although disregarded in the old scientific literature, these two kinds of sensibility have been long familiar to ordinary observation. "At night all cats are gray," says the

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[1] This is the name of the small hollow which exists in the middle of the yellow spot and on which the image is focused in central vision.

[2] La Vision, Étude physiologique, 8vo., 218 pp., Octave Doin, 1898, pp. 47–48.

[3] La Lumière et les Couleurs au point de vue physiologique, vol. 1, 8vo, 352 pp., Bibliothèque scientifique contemporaine, Baillière et fils, 1888. See p. 209.

proverb, and how often have we not repeated: "It is too dark to distinguish colors." The poet Racan, who had an affection for nature so rare in his time, tells us furthermore in his Bergeries:

> "The shades of night with their own dusky hue
> Alike the meadows and the fields imbue."[1]

Before taking up the study of Charpentier's researches we will first consider the variation of chromatic sensibility in the different parts of the retina. To quote M. Parinaud: "Chromatic sensibility decreases from the center to the periphery, whether or not the retina be adapted to obscurity. Besides, it decreases unequally for the different colors. The radial distance at which a color ceases to be perceived varies according to the intensity of illumination, the saturation of the color, and in addition according to the extent of the colored surface. It is therefore difficult to define the extent of the field of vision for each color. The relations which these fields of vision bear to one another are, on the contrary, quite fixed. The fundamental colors are lost to perception in passing from the center to the periphery of the retina in the following order: Green, red, yellow, blue. It may be said with truth that the peripheral parts of the retina present a normal Daltonism; indeed, in certain regions one can observe color-blindness for the green and red, with normal vision for the yellow and blue, as in Daltonism."[2]

Mention must also be made of the faculty of visual definition—that is to say, of the faculty of perceiving forms. This attains its greatest perfection in the fovea, and decreases rapidly with the distance therefrom; but, as stated above, when the retina is strongly adapted the fovea is relatively much less sensitive than the exterior parts of the retina. The latter tend to supplement the central portions, and thus the definition increases from the center to the periphery.

Let us now study anew the same phenomena under the direction of Charpentier. There will necessarily be some repetition, but it may not be without interest to clearly understand in what respects this investigator agrees with the former and in what he differs. A résumé of his investigations has been given in the treatise already cited, "La Lumière et les Couleurs," and also in an article on "The origin and mechanism of the different varieties of luminous sensations."[3]

"In exploring, by means of a special photometer and by the method of minimum perceptibility, the sensitiveness of different parts of the retina, I have shown," says Charpentier, "that the acuteness of perception of uncolored light (that is, white light, including the different shades between white and black) is equally great on every part of the retina except at the center, where it is least. Color sensibility

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[1] C'est l'ombre de la nuit, dont la noire pâleur
Peint les champs et les prés d'une même couleur.

[2] Page 71.

[3] La Revue Générale des Sciences Pures et Appliquées, July 15, 1898. The same review had published M. Parinaud's article on the functions of the retina (April, 1898).

varies in an entirely different manner; it diminishes regularly from the center to the periphery, where it has even appeared to certain experimenters to be entirely absent.[1] * * * The sensation of white, which according to Helmholtz is the most complex sensation, is, on the contrary, the most simple and the one most easily produced. If any simple spectral color be presented to the eye, the first sensation produced (that which requires the least light for exciting the retina) is a purely colorless sensation. To produce the idea of color it is necessary to more strongly excite the retina, to present to it a much stronger stimulus. * * *

"Then, again, these two functions may vary independently of one another, not only on account of their different localization, but also because of the different influences exerted on them by certain physiological conditions. Thus I showed in 1878 that the adaptation of the eye to obscurity increases the luminous sensibility and hardly affects the chromatic sensibility; hence the fact, inexplicable in the Helmholtz theory, that a simple color seen by an eye that has been kept in darkness is perceived mixed with white. If this is taken together with the fact that a pure color that appears saturated at the center of the retina, appears more and more mixed with white (finally becoming entirely white or gray) in proportion as it is viewed more indirectly, it is easily seen with what facility white is produced by a physically simple excitation. * * *

"On December 27, 1880, I differentiated a new function of the retina, independent of luminous sensibility and of chromatic sensibility, namely, visual sensibility. I showed that the perception of a group of small luminous points in central vision passes through two phases,[2] precisely analogous to the two phases of color perception; the one of indistinct vision (gross visual sensibility), the other of distinct vision (visual sensibility, properly so called). The first requires for its excitation less light than the second and may vary independently of the other."

After having alluded to the researches of M. Parinaud of 1891, M. Charpentier continues as follows:

"During these two years MM. Macé de Lépinay and Nicati published their valuable researches on the distribution of brightness and of visual definition in the spectrum, and discovered the important fact that luminous intensity and visibility do not vary in the same ratio from one color to another, the brightness relatively predominating in the more refrangible part of the spectrum."

These statements, which are taken from the article in the Revue Générale, could be advantageously completed by the details given in the treatise on light and color; but, for the sake of brevity, we will simply give the results of the experiments made for the purpose of determining the ratio between the intensity required for producing a luminous sensation and a clearly distinguishable color sensation throughout the different parts of the spectrum.

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[1] Charpentier adds that this is erroneous.

[2] By direct vision, is understood vision by means of the fovea; and by indirect vision, that by means of the eccentric parts of the retina.

Region of spectrum.	Ratio.
Extreme red	3.6
Orange	5.5
Yellow	9.6
Green	196
Blue	625

It should be remarked that these ratios[1] were determined for an eye kept for twenty minutes in darkness. If an eye not adapted had been tested the above ratios would have been reduced, as it is well known that its luminous sensibility is much less. It is, however, a very interesting fact that the quantity of light necessary for the perception of color remains very nearly constant. Furthermore, if one adds white light to a mono-chromatic light, the quantity of the latter necessary for the recognition of its color remains almost invariable. If the results obtained by M. Charpentier and M. Parinaud are compared, it will be seen that they differ but slightly. According to M. Parinaud, red cannot give rise to a luminous sensation without color, even in indirect vision, and, on the other hand, in the yellow spot all the colors appear at first sight as colored. Although M. Charpentier denies these propositions, he nevertheless recognizes that chromatic sensibility is best developed at the center of the retina. M. Parinaud, on his side, formally recognizes the decrease of chromatic sensibility from the center to the periphery of the retina, and even his denial that red can produce a luminous sensation without color is not absolute, since he recognizes that certain parts of the retina can not perceive this color.

As we have stated above, the German physicists and physiologists took up the study of the same phenomena after the French savants, and, judging from the excellent reviews published by M. Victor Henri in successive volumes of "L'Année Psychologique," the phenomena observed across the Rhine are in exact agreement with the enunciations of M. Parinaud. It is, however, to be regretted that his frequent visits to the German laboratories have prevented M. Henri from reminding Koenig and Von Kries to respect the rights of priority of Charpentier and Parinaud. Professor Nuel, of Ghent, in reviewing the researches of Von Kries in "Les Archives d'Ophtalmologie," adds to his analysis the following reflections: "It seems to me that the authors across the Rhine are too neglectful of the preponderating merit which our French collaborators have had in the elaboration of these new ideas." Without wishing to dwell longer than necessary on this detail, I have thought that it should not be passed over in silence.

The first publication of Von Kries on this subject appeared in 1894, and (thanks to the review by M. Victor Henri) we will be able to summarize his results. Hillebrand had shown in 1889 that if the eye be adapted to obscurity, a spectrum whose brightness is continuously

[1] La Revue Générale, etc., July 15, 1898, p. 214.

decreased will finally appear as an illuminated colorless band. Repeating this experiment, Von Kries showed that this is only true for indirect vision for the fovea, although less sensitive to the simple luminous sensation, perceives the colors disappear without becoming white.

In the same year Koenig made similar observations.

In 1895 Hering, in an important paper on the Purkinje phenomenon, of which we will speak later, established the fact that with dark surroundings colors appear less saturated, a result of great importance, according to M. Henri, although well known for a number of years, as we might add.

In 1896 Von Kries established the fact that in the fovea the ratio of the intensities of the different spectral colors does not vary with the illumination, as is the case in indirect vision. He also showed that red is an exception to the law according to which spectral colors appear as uncolored in indirect vision.

In 1897 the investigations on visual sensations rapidly increased, especially in the laboratory of Von Kries at Freiburg, in Breisgau.

Von Kries, in collaboration with Dr. Nagel, was engaged particularly in experimentally testing Hering's law in regard to the white value of a mixture of two spectral colors, and they discovered that, even if it be verified by observations made with the yellow spot, it is no longer the same in indirect vision by means of a retina adapted to obscurity.[1] They also studied the variations in the brightness of different colors, according as the eye is adapted to the full daylight or to obscurity. They showed that in central vision colors never give rise to the sensation of gray, as in peripheral vision, and finally they determined the sensitiveness of the different parts of the retina to various chromatic excitations.

Interesting comparisons might be made between their numerical results and those obtained by MM. Charpentier and Parinaud, but taken as a whole they do not bring to light anything new. Kries and his collaborators have, however, made curious observations on subjects totally or partially color-blind, of which we shall have occasion to speak later. Concerning some of the experiments of Shermann that tend to prove, in contradiction to Kries and Koenig (and let us add in contradiction to Parinaud, but in agreement with Charpentier), that points very feebly illuminated are seen as uncolored by the yellow spot, M. Henri objects that the fixation of the images is very difficult under these circumstances and consequently these images may very easily wander from the aforesaid spot.

By this brief analysis of the German researches it may be seen that as a whole they have fully confirmed the results previously obtained by Charpentier and Parinaud. Before taking up a study of the physiological conditions which appear to underlie these phenomena

[1] It is unfortunate that M. Victor Henri, ordinarily so exact, has given in his analysis a table of figures difficult to interpret.

it remains to be shown how they account for certain well-known facts which have remained isolated and have not appeared to be logically connected with the rest.

In 1825 Purkinje pointed out the change which a color undergoes if its intensity be gradually diminished; for example, if we take two pieces of colored paper, the one red and the other blue, the latter of which, under a moderate illumination, appears darker than the former, and gradually decrease the illumination of the chamber in which they are placed, the blue paper will gradually be seen to become relatively lighter than the red. Indeed it is possible, by still further diminishing the intensity of illumination, to reach a stage when the blue paper will appear whitish gray and the red paper entirely black. This is called the Purkinje phenomenon. Parinaud, in a résumé of his previous studies in his treatise on vision,[1] explains the phenomenon in this manner: "It is not the differences of intensity of the colors that produces the phenomenon, but differences in the illumination of the retina which observes them. The phenomenon is due, not to an objective, but to a subjective cause, and finds its natural explanation in the properties of the retina. It results from the unequal influence of the adaptation of the retina to rays of different refrangibility, and also from the fact that adaptation only affects the luminous value of colors and not the color sensation itself."

Hering, in an article published in 1895, arrived at analogous conclusions. He discovered, in fact, that the diminution in the intensity of colors alone is not sufficient to produce the Purkinje phenomenon; this manifests itself if the room in which the subject is placed be darkened, and is the more pronounced the more perfectly the eye is adapted to obscurity. It is more characteristic of indirect than of direct vision.

In 1896 Von Kries showed that the Purkinje phenomenon is absent in direct vision, and for indirect vision its intensity is proportional to the degree of adaptation of the eye to darkness.

All these results, according to Parinaud, appear fully explained by the fundamental phenomena discovered by himself and Charpentier. The latter, however, explains the results in an entirely different manner. By observing for each spectral color the additional illumination which is necessary to enable the eye to distinguish the difference between the new and the previous illumination, he deduces a curve showing the relation between the intensity of the sensation and the intensity of its stimulus, according to Fechner's principle, without, however, being able to verify the law which bears the latter's name. He has thus established that the less refrangible colors gain much more in brightness than the more refrangible ones when the intensity of the light is continuously increased.[2] From this observation the Purkinje phenomenon can be deduced. It will also be remarked that

[1] Op. cit., p. 67.

[2] La Lumière et les Couleurs, p. 333.

these experiments were made on eyes adapted to obscurity. Under these circumstances it might possibly be questioned if, when the luminous points observed become sufficiently bright, the adaptation of the corresponding points of the retina does not diminish. However, if this were the case, it should result in increasing the smallest perceptible difference for the more refrangible colors. It is quite evident that Charpentier's explanation only differs in form from that of Parinaud. As a counterproof it would be interesting to repeat Charpentier's experiments on eyes adapted to light, the eye being subjected to full daylight between two consecutive observations. In passing I might call attention to a complex phenomenon, easily observable, in which the Purkinje phenomenon is greatly exaggerated by the effect of contrast.

In a poorly illuminated church just at daybreak the stained-glass windows at a certain moment assume an aspect that is at first surprising; of all the colors, the blue alone appears with any brilliancy. It would be superfluous to emphasize the fact that the contrast of the yellowish color of the interior light is added to the Purkinje phenomenon.

There is another fact to which I have not as yet alluded, but which I have always observed in myself. When attempting, in a poor light, to read fine print I instinctively make use of monocular vision. This appears to result from the fact that under these circumstances one naturally has recourse to indirect vision, which is alone benefited by adaptation to obscurity and which is difficult to adjust to binocular vision. It would be possible to continue the enumeration of phenomena related to the fundamental observations of Charpentier and Parinaud, but it is better to turn now to the examination of the anatomical structures and the chemico-physiological phenomena which appear to be related to the characteristic perceptions which we have been discussing.

II.—PHYSIOLOGICAL PHENOMENA.

It is well known that the optic nerve, after having entered the eyeball at the blind spot, designated as the papilla, spreads out in such a manner as to form what is called the internal layer of the retina, but which could as well be called its external layer, for while it is internal from the geometric standpoint, as being nearer to the center of the eyeball, it is external with respect to the tissues which envelop the eye. The nerve fibers thus spread out curve back toward the exterior, and finally terminate in the layer of rods and cones, or Jacob's membrane, about 50 microns thick. This layer is covered with pigmentary cells, in which the terminal organs of the optic nerve are more or less buried. It should be pointed out, furthermore, that the nerve fibers, before reaching the membrane, penetrate, one by one, large cells which are provided with many prolongations toward the external layers. This description is quite abbreviated, for not less than 10 different layers are distinguishable within the thickness of the retina. An examination of the different regions of the retina shows that the cones, which are on the average 20 times less numerous than the rods, alone exist in the yellow spot, but are more and more outnumbered by the rods as one approaches the periphery. The cones of the "macula" or yellow spot are, besides, more elongated and smaller than those of the rest of the retina. The multipolar cells, referred to above, increase in number and are only bipolar in the macula, but they disappear in the fovea which lies at the center of the spot.

Besides these details in regard to the constitution of the retina, those concerning visual purple or erythropsine must be given. For many years certain anatomists had called attention to a red pigment in the retinas of certain animals, but the credit of emphasizing the importance of this substance belongs to Boll.[1] In 1876 he discovered the existence of a red coloring matter in the rods of the frog, which undergoes a change if subjected to the influence of light. This material, which remains unchanged in frogs kept in obscurity, becomes paler when the animals are exposed to the light, and if they are kept in sunlight the retina becomes colorless. Retinas removed in darkness may take several minutes to decolorize in daylight. In mammals the decolorization is much more rapid. Boll established, furthermore, that the color lost in frogs exposed to sunlight is reproduced in darkness, but he was not able to recognize the nature of this coloration, which he was led to attribute to a lamellar structure of the rods and not to a coloring matter. Kühne succeeded, on the other hand, in isolating the coloring matter by means of a solution of bile or of cholate of sodium. The solution of visual purple thus obtained changes from red to yellow under the influence of light, and finally becomes colorless. This decoloration, according to Kühne, is, moreover, much more rapid in that region of the spectrum comprised between the greenish-yellow and the indigo than elsewhere. Red is the least active color, even less active than the ultraviolet rays.

The yellow material, produced by a partial decomposition of the visual red, follows a slightly different law of decoloration. The chemical action of radiations being related to their absorption, the decolorizing action, nearly absent in the red and yellow, is at a maximum in the violet and is quite strongly developed in the ultraviolet.

Without wishing to enter into a discussion of the details of these experiments, we can hardly omit reference to veritable photographs, known under the name of optograms, which Kühne has been able to produce on the retinas of rabbits and frogs. It might be pointed out that, disregarding certain apparent exceptions, nocturnal animals have a retina abundantly provided with visual purple, while the purple, as well as the rods, is wanting in those animals which sleep at night—for example, poultry.

The visual purple has still another characteristic property. Previous

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[1] An article by Weiss on the chemical theory of vision, in La Revue Générale, March 30, 1895, is freely made use of in the résumé of this subject.

to the discovery of Boll, Helmholtz had discovered the phenomenon of fluorescence in the retina; Ewald and Kühne established the fact that this property belongs only to those parts of the retina which contain the purple. In order to verify this in a marked manner it is necessary, however, to experiment with an unbleached retina from the living subject. A retina saturated with purple gives rise to a whitish fluorescence, which changes to greenish as soon as the retinal yellow predominates, and finally becomes green for a decolorized retina. These observations, of a physical character, bring us at once to a consideration of the principal hypotheses which have been suggested to connect them with the phenomena of sensibility discussed in Part I. The theories (properly so called) which attempt to explain in a systematic manner the origin of color sensation will be reserved for Part III.

From 1881 to 1885 Parinaud published a series of studies in which he emphasized the separate and distinct rôles played by the rods and the cones in vision. As stated above, neither rods nor visual purple are found in the fovea of which the sensitiveness is not at all increased by darkness; and, moreover, since darkness influences only the luminous sensation and not the chromatic sensation, we may conclude that the cones are the organs of color sensation, while the rods and the visual purple have nothing to do with it. Parinaud finds a confirmation of this opinion in persons afflicted with hemeralopia; that is to say, incapable of seeing in a dim light. In these the functions of the fovea, where there is no purple, are intact; and on the other hand, hemeralopia carries with it no deterioration of color vision. Moreover, in Daltonism the luminous value of the colors not perceived is unaffected, at least if the retina be adapted to obscurity.

Later, in 1894, Parinaud emphasized the rôle which the fluorescence of the retina plays in luminous sensation. Helmholtz denied this explanation, basing his argument on its greenish coloration. This coloration is, moreover, not essential, as we have seen, and there can, moreover, be no necessary correlation between the objective properties of the luminous agent and the sensation which it provokes; however, it does not seem to us that Parinaud gives any proof of his own hypothesis, since, as fluorescence constantly accompanies the purple and never exists without it, it therefore appears impossible to separate its influence from that of the other properties of the purple. Nevertheless, it should be pointed out that the sensation provoked by the blue, violet, and ultraviolet radiations on a retina previously subjected to darkness presents the special characteristics of sensations produced by fluorescing bodies, and that the highly refrangible radiations are at the same time those which affect the purple and produce the phenomena of fluorescence.

However this may be, Parinaud admits that there is a certain difference between the action of visual purple and the fluorescence of inorganic substances. The latter does not appear to be accompanied by any disengagement of electricity or heat, while several experimenters have verified that it is otherwise in the case at hand. Since 1874—that is to say, before the discovery of visual purple—Dewar has recognized that the action of light on the retina is accompanied by the development of an electro-motive force, measurable by means of a galvanometer. Having confirmed this observation, Johannes Chatin established the effect of obscuration on the intensity of the current and the unequal action of the different radiations; in addition, he verified that the greatest electro-motive force is found in those species in which the purple predominates, as in the lobster. All these circumstances tend to show that the disengagement of electricity is principally caused by physico-chemical action that has its seat in the visual purple.

The conceptions of Parinaud, which may indeed be reduced to the perception of colors by the cones and of colorless light by the rods under the action of the purple, have been readopted by Von Kries since 1894, and, indeed, M. Victor Henri, in referring to them, constantly calls it the theory of Kries. Parinaud, who claims very properly the rights of priority, moreover adds that Schultze, as early as 1866, pointed out the probable difference in the rôle of the cones and that of the rods, a difference which he based on their unequal distribution in the retina and on the diminution in the intensity of color vision at its periphery, where the cones are rare. Schultze's opinion, however, remained unnoticed, but fortunately it has now been completed by the discovery of the purple and all the investigations that have been made upon it. Therefore Schultze appears to deserve an eminent place in the development of the subject near Parinaud. The investigations of Koenig and of Kühne appear to be much more original than those of Kries; for by comparing the absorption curves of visual purple and yellow, in different parts of the spectrum, with those of the luminous impression and its variation for the different spectral colors, they have truly completed the results of Parinaud. In the article of Weiss, already referred to, I found some very curious curves, showing the proportionality between the luminous impression and the absorption of the rays by the visual purple. We shall have occasion to return to these investigations in Part III.

III.—THEORIES OF COLOR PERCEPTION.

In all that precedes we have seen that certain anatomical elements appear to be involved in color perception and that the different radiations exercise an influence more or less great on the luminous sensation, but nothing has so far been said concerning the mechanism of differentiation in color perception. Here it must be clearly recognized that we are on unsafe ground; on account of the lack of sufficient experimental evidence, the hypotheses become more audacious and are often too far removed from the possibility of experimental control.

Nevertheless, a rapid review of the principal hypotheses which have been advanced by scientists may not be entirely without interest.

The first hypothesis that presents itself to the mind is the assumption that for each wave length of light there corresponds a distinct kind of excitation of the optic nerve, and consequently a distinct sensation, but this idea, which at first sight appears so simple, is open to a very grave objection, which has given birth to the trichromatic theory which the name of the great Helmholtz has endowed with a remarkable authority, notwithstanding that he is not the author of the theory; neither does he claim authorship, for he has himself declared that it was borrowed from Young. It seems, moreover, that it was developed several years before the publication of his treatise on physiological optics, with all the accompaniment of general conceptions that give to it its philosophic scope.

We now turn to the consideration of a treatise that appeared in 1855, entitled, "Electro-dynamisme vital," under the nom de plume of Philips, under which the real author, M. Durand (de Gros), then proscribed, hid his identity. The basis of the trichromatic theory is found in the doctrine of the specific energy of the nerves, according to which each nerve filament can only act in a single manner, and consequently can only provoke sensations differentiated by their intensity. Applying this theory to the whole nervous system, Durand summarizes it as follows:

"1. The nature of each animal or vegetal function depends essentially on the characteristic activity of its corresponding nerve fiber or fibers.

"2. The characteristic activity of every nerve fiber is its invariable attribute."[1]

Applying this theory further on he expresses himself thus:

"It would be carrying these principles too far to assume the existence of a distinct faculty and of a distinct individual nerve fiber for each of the varieties of sensation that can be experienced. It is conceivable, indeed, that the same agent might excite the same sensitive faculty with an unequal intensity * * *. Thus, although still remaining invariable in its nature, a sensitive faculty might vary in the degree of excitation to which it is susceptible, and, moreover, it is very easy to comprehend that two or more sensitive faculties excited simultaneously might give rise to a compound sensation, which it would consequently be improper to attribute to a new elementary faculty or to a particular nerve fiber."[2]

In a special consideration of the sense of sight Durand remarks that, although the advocates of the theory of special nerve fibers are correct in not admitting that the nerve fibers affected in color sensations are localized in distinct portions of the retina (under these conditions objects would change color if displaced), there would be no objection to a different subdivision of the fibers. He states that

[1] Page 57. [2] Page 154

we are not obliged to assume that each kind of fibers constitutes a bundle of which the base forms a continuous portion of the field of view. To quote Durand: "On the contrary, we may conceive that these three different kinds of fibers are intercombined in their simple units in such a way that all parts of the retina present a homogeneous mixture of these fibers, so that on whatever point of the retina a ray of a given color should fall it would be sure to encounter there a corresponding fiber adapted to receive its impression."

We have just seen that Durand assumes that three kinds of fibers are sufficient to produce all color sensations, and this is also the number adopted by Helmholtz, but the latter attributed to them the perception of the red, green, and violet sensations, while Durand considered the red, yellow, and blue sensations as primary.

As it is hardly possible to assume that the light waves are transmitted as such through the nerve fibers; the velocity of propagation of nerve excitations being incomparably less than that of ether waves, it is evident that one must assume that they undergo some transformation in the retina. This explains why the theory of Helmholtz is in very good agreement with the hypothesis that there is an intervening step of a chemical nature between the luminous radiation and the excitation of the optic nerve. Koenig has remained faithful to this theory, although he includes a fourth sensation, the gray sensation, due to the decomposition of the visual purple. Experiments seem to him to indicate that the retinal yellow is involved in the production of the blue sensation; the red and green sensations he attributes to substances still unknown. The inclusion of the gray sensation appears to me, however, to necessitate the assumption of a fourth kind of nerve fiber, and in addition there would still remain to be discovered two new visual substances.

Hering assumes that there are only three visual substances, but he boldly attacks the dogma of specific nerve fibers, for he supposes that the opposite chemical reactions [anabolic and catabolic changes], which each of these three substances is capable of undergoing, produce the complementary sensations (green, blue, and black, corresponding respectively to red, yellow, and white).

Ebbinghaus is said to have adopted this theory, completing it by means of some recent discoveries; but it appears to us, on the contrary, that he has altered the fundamental idea, for he assumes that each of the substances is capable of undergoing not two opposite chemical reactions, but a single reaction in two stages. The absorption spectrum of visual purple has its maximum between the D and E lines of Frauenhofer; the yellow, resulting from the partial decomposition of the red, has its maximum decomposition between the F and G lines. But the study of a subject affected with Daltonism, for whom there are only two colors—yellow and blue—has shown that while the region of the spectrum in which the blue is for him most brilliant coincides invariably with the region of maximum absorption for visual yellow, the region corresponding to a maximum intensity of the yellow may occupy two different positions, according to the subject selected. Hence this peculiarity would correspond exactly to the existence of two different purples, the one red and the other violet, the absorption bands corresponding to the two varieties of Daltonism.

From these facts Ebbinghaus concludes that the visual purple is involved in the perception of yellow, and the visual yellow in perception of blue. In addition to these two substances, which are derived from one another, he assumes the existence of a third, namely, visual white, which by its transformation gives rise to the perception of white and gray. In normal eyes he assumes a new substance which, by transforming itself like visual purple, would give rise to the perceptions of red and green. It is quite evident what an important rôle unverified hypotheses play in this theory as in that of Koenig. Nevertheless, it might be remarked that the study of subjects afflicted with achromatopsia, more or less complete, is susceptible of furnishing many interesting results.

Von Kries and his pupils have for the most part been engaged in observations of this nature. But if they believe that they have overthrown Hering's theory, others like Kirschmann think that they can show the insufficiency of every theory admitting only three sources of luminous sensations. On the basis of a study of color-blindness the latter believes that he has established that the customary division of cases of color-blindness into blindness for blue and yellow and blindness for red and green is insufficient to explain the facts.

With such an accumulation of data some are very likely to be in contradiction to the others, and hence there rises the need of a synthetic treatise criticising the different theories and combining them to form a new one which can coordinate all psychological, physiological, pathological, histological, and chemical data appertaining to the subject of color vision. M. Victor Henri is of the opinion that a publication of Prof. G. E. Müller, of Göttingen, on the "Psycho-physics of visual sensation" meets this desideratum. A very interesting analysis of his results is to be found in the fourth volume of L'Année Psychologique, but we shall have to limit ourselves to a statement of the conclusions reached. All visual sensations are based on six chemical processes of the retina, corresponding to the sensations of white, black, red, green, yellow, blue; the author adopts, moreover, on the whole, the views of Von Kries and Parinaud in regard to the rôle of the cones and rods. He, however, contends that the visual substances are the same in both.

In a separate publication on the visual sensations produced by the galvanic current, Müller announces it as a general fact that when the current passes through the eyes toward the back of the head the subject experiences a bright blue-red color sensation, while if the current passes in the opposite direction the sensation produced is that of a dark greenish-yellow. Here is a confirmation of the theory of reversed chemical reactions on the retina. It would seem to us that this would be rather an argument in favor of the three substances of Hering than of the six substances of Müller, but possibly we have not entirely comprehended his theory, a disadvantage often unavoidable when one works with a mere résumé, however well made. We are not confronted by the same difficulty in reviewing the theories of MM. Nicati and Charpentier, that of the former having been published in L'Annales d'Ophtalmologie, January, 1895. After having pointed out that luminous sensations of very small dimensions, although corresponding to a retinal field smaller than the rod itself, are recognized in their proper colors, and having concluded therefrom that the same rod must be capable of transmitting different colors, the author assumes that there should correspond to the different chemical actions, produced by the different radiations, variations in the quantity and tension of the electric currents engendered by them. The short radiations having an intense and rapid action, should develop currents of maximum quantity and minimum tension. These can only flow through nerve filaments of small resistance—that is to say, the short and thick ones—while the currents of high tension are able to follow the long and thin filaments, which offer a greater resistance. These different currents are discharged upon the optoblasts, which are differentiated by the influence of habit and heredity, and hence result the differences in color sensations.

Much more subtle and more complex in its details is the theory of Charpentier. As we have already pointed out, he distinguishes, together with Parinaud, three functions of the retina—luminous sensibility, chromatic sensibility, and visual sensibility. Up to this time we have not dwelt much on the latter, but it is to play a preponderating rôle in the theory we are about to discuss, and it is therefore necessary to dwell on this function somewhat before taking up the consideration of the theory.

If, while in darkness, we determine the minimum illumination necessary for the perception of a luminous surface of considerable extent, we find there is no sensible difference in the aspect of that surface, whether it be brightly or dimly illuminated; but if the surface be sufficiently small it is seen under a minimum illumination as a diffused spot with indistinct outlines always much larger than it really is. A sharp perception of its form and dimensions requires a stronger illumination.

The enlargement of a dimly illuminated image is explained by the diffusion of the luminous impression on the retina or in the nerve centers, a fact which has been thoroughly verified, but distinct vision evidently requires an additional stimulus or the excitation of a new physiological element.

By means of very small holes, a millimeter apart, in an opaque screen, Charpentier has shown that from two or three times to eighteen or twenty times more light is needed for distinguishing the luminous points than for merely apprehending the primitive luminous sensation. The difference is still greater for an adapted eye, as we might have foreseen, since it is known that adaptation does not develop the sensitiveness of the yellow spot, where visual perception is at its best. Continuing the study of the phenomenon, if the small points are successively illuminated with the different spectral colors, and if the ratios of the intensity required for the luminous sensation and that permitting a distinction of the points be determined, it is observed that these ratios exceed unity in proportion as the color is more refrangible. In this connection we may recall analogous facts relative to the distinction between luminous sensibility and color perception. This general agreement, expressed in exact figures, is transformed into an almost rigorous proportionality, for the ratio between the intensities required for distinct vision of the points and for the perception of their color only varies between 1.80 and 1.93, according to the spectral color employed.

From these facts Parinaud concluded that the retinal elements involved in distinct vision are the same as those involved in color perception, to which conclusion, however, Charpentier takes exception. The latter points out that the distribution of visual sensibility throughout the extent of the retina is not the same as that of color perception, which decreases regularly from the center of the retina to its periphery, while visual sensibility decreases much more rapidly. On the other hand, in the fovea itself the perception of colors is almost zero, while the visual sensibility has there its maximum.[1] If it be remarked that luminous sensibility is also very feeble in the fovea, one is led to the conclusion that chromatic sensibility exists only in those regions where both luminous and visual sensibilities exist at the same time, and moreover that it undergoes variations throughout the extent of the retina, which correspond sufficiently well to the mean of these two functions.

One is thus led to the view that color sensation is due to the combined action of the elements of both the luminous and visual sensibilities. It is thus induced by a physiological fact, due to the simultaneous existence of two distinct impressions produced in the organ of sight by luminous rays. Starting out from this conception, naturally suggested by the facts, Charpentier formulates a bold theory of which he is the first to recognize the highly hypothetical character, but which, it appears to us, deserves a detailed analysis.

In seeking the possible nature of the two fundamental actions we are led to the view that the former or photoæsthetic action (being photochemical) is due to the visual purple. The second or visual action

[1] Corresponding with this fact, we find that the nerve cells in relation with the macula are bipolar and not multipolar, as elsewhere in the retina.

presents the peculiarity of being approximately proportional to the absolute energy of the light, the intensity of which has been determined in the different parts of the spectrum by Langley. From this proportionality we may conclude that the light acts by itself in the visual function, being without doubt integrally absorbed by a material which is perhaps the pigment of Jacob's membrane—a pigment which surrounds and separates from one another the rods and the cones. This absorption of light would heat the pigment and therefore the visual elements, and might generate at the same time thermo-electric currents. Vibrations of an indeterminate nature should thus be produced in the nerve fibers, and these vibrations should be similar to each other as to form and wave length, whatever be the nature of the exciting rays, since it is the pigment which directly produces the excitation; the visual elements, therefore, can not of themselves provoke a color sensation. It is quite easy to produce the luminous sensation independently by means of any spectral ray whose intensity is too feeble to act on the visual element, and, as is well known, a bluish-white sensation is produced by all colors. On the other hand, the visual sensation may also be isolated by fatiguing the eye by a white light, sufficiently intense to decrease the excitability of the photoæsthetic element below that of the visual element, under which conditions even the red does not appear colored. For the same reason all colors, if of sufficient intensity, give rise to a white sensation, and hence the above conjectures are found to be verified.

This granted, the calorific action and the chemical action of light both give rise to undulations in the nerve fibers, and it is probable that their wave lengths differ, but it must be assumed that these lengths bear a simple ratio to one another, since they must give rise to a complex vibration of a definite nature to produce a definite color sensation. Recalling that the relative amplitude of the two kinds of vibrations varies with the different colors, that for a given amplitude of visual vibration the amplitude of the photochemical undulation increases rapidly from the red to the violet, it will be recognized that the form of the undulation should vary with the ratio of the two amplitudes—that is to say, with the color.

Besides, M. Charpentier has demonstrated the existence of a reaction time in the action of light on the organ of luminous sensibility—a reaction time which increases from the red to the violet—while the reaction time relative to visual sensibility does not vary with the color. From this there results a new cause for variation in the form of the resulting undulation, since the undulation of photochemical origin does not coincide in phase with the undulation of pigmentary origin. On the basis of this double difference of phase and relative amplitude, and making certain arbitrary assumptions in regard to the relative length of the two waves, as well as concerning the two elements varying with the colors, M. Charpentier has constructed a number of curves which perfectly explain the laws of color mixture, especially that of complementary colors.

Aside from its ingenuity, this theory presents a curious peculiarity in giving an objective basis to the æsthetic affinity of colors and certain sounds, an affinity so definitely recognized in the German language and by the majority of authorities on æsthetics. This affinity is, however, in direct contradiction with physical phenomena, since colors depend on the number of vibrations in a unit of time, and therefore correspond to the pitch of a sound and not to its quality. We have pointed out in a study on the relations between painting and music[1] how we had to recognize that the æsthetic imagination struggles against this purely scientific objection, although we ourselves were disinclined, for the above reasons, to admit the similarity of color in light and timbre in sound. Right or wrong, it is a satisfaction to us to see that this contradiction can be removed by supposing a transformation to be effected in our organism, thus permitting the difference in colors to rest (just as those of quality in sound) on a difference in the form of the vibrations or undulations. However this may be, M. Charpentier has endeavored since 1885, when he first formulated his theory of color vision, to verify it by experiments which, however, only appear to have had a bearing upon the question of retinal vibrations, on which subject he has published numerous articles since 1890. A list of these is given in his article in the Revue Générale des Sciences.

It is to be hoped that he will not remain alone in the exploration of this field, and that the German school will devote to it a little of the zeal it devotes to the study of vision.

In bringing this article, which is devoid of any personal pretensions, to a close, we can but regret its insufficiency in every respect. Our aim will, however, have been attained if we have succeeded in directing the attention of the reader unfamiliar with the subject to the great interest of the researches on the subject we have specially considered, and on still others tending to modify greatly the science of physiological optics.

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[1] Revue Philosophique, August, 1885.

SOME CURIOSITIES OF VISION.[1]

By SHELFORD BIDWELL, Esq., M. A., LL. B., F. R. S., M. R. I.

The function of the eye, regarded as an optical instrument, is limited to the formation of luminous images upon the retina. From a purely physical point of view it is a simple enough piece of apparatus, and, as was forcibly pointed out by Helmholtz, it is subject to a number of defects which can be demonstrated by the simplest tests, and which would, in a shop-bought instrument, be considered intolerable.

What takes place in the retina itself under luminous excitation, and how the sensation of sight is produced, are questions which belong to the sciences of physiology and psychology; and in the physiological and psychological departments of the visual machinery we meet with an additional host of objectionable peculiarities from which any humanly constructed apparatus is by the nature of the case free.

Yet in spite of all these drawbacks our eyes do us excellent service, and provided that they are free from actual malformation and have not suffered from injury or disease, we do not often find fault with them. This, however, is not because they are as good as they might be, but because with incessant practice we have acquired a very high degree of skill in their use. If anything is more remarkable than the ease and certainty with which we have learned to interpret ocular indications when they are in some sort of conformity with external objects, it is the pertinacity with which we refuse to be misled when our eyes are doing their best to deceive us. In our earliest years we began to find out that we must not believe all we saw. Experience gradually taught us that on certain points and under certain circumstances the indications of our organs of vision were uniformly meaningless or fallacious, and we soon discovered that it would save us trouble and add to the comfort of life if we cultivated a habit of completely ignoring all such visual sensations as were of no practical value. In this most of us have been remarkably successful, so much so that, if from motives of curiosity or for the sake of scientific experiment, we wish to direct our attention to the sensations in question and to see things as they

[1]From Proceedings of the Royal Institution of Great Britain, Vol. XV, Part II, No. 91, April, 1898, pp. 354–365. Read at weekly evening meeting, Friday, March 5, 1897.

actually appear, we can only do so with the greatest difficulty; sometimes, indeed, not at all, unless with the assistance of some specially contrived artifice.

I propose to discuss to-night a few of the less familiar vagaries of the visual organs, and will do my best to assist in the illustration of them. But it will be my part merely to provide the apparatus for the experiments; the experiments must themselves be carried out by each of you individually. Some of them will, I am afraid, be found rather difficult; success will depend mainly upon your power of laying aside habit and prejudice and giving close attention to your visual sensations. I hardly dare to hope that everyone present will observe all the peculiarities and defects which it is intended to demonstrate, but in case of failure I generally find that there is a comfortable tendency to attribute it not to any deficiency in the observer's power of concentrating his attention, but to the fact that his eyes are not as other men's, and are free from the particular defect which it is desired to bring into prominence. Of course, anyone is welcome to such an entirely satisfactory opinion.

Among the most annoying of the eccentricities which characterize the sense of vision is that known as the persistence of impressions. The sensation of sight which is produced by an illuminated object does not cease at the moment when the exciting cause is removed or changed in position, but continues for a period which is generally said to be about one-tenth of a second, but may sometimes be much more or less. It is for this reason that we can not see the details of anything which is in rapid motion, but only an indistinct blur, resulting from the confusion of successive impressions. When I turn this disk, which is painted in black and white sectors, you soon lose sight of the divisions, and if the speed is high enough the whole surface appears to be of a uniformly gray hue. If we illuminate the rotating disk by a properly timed series of electric flashes, it looks as if it were at rest, and in spite of the intermittent nature of the light, the black and white sectors are seen quite continuously, though as a matter of fact the intervals of darkness are very much longer than those of illumination.

The persistent impressions which we have been discussing are often spoken of as positive after-images.

There is one very remarkable phenomenon accompanying the formation of positive after-images, especially those following brief illumination, which seems, until comparatively recent times, to have entirely escaped the notice of the most acute observers. It was first observed accidentally by Prof. C. A. Young, when he was experimenting with a large electrical machine which had been newly acquired for his laboratory. He noticed that when a powerful Leyden jar discharge took place in a darkened room, any conspicuous object was seen twice at least, with an interval of a trifle less than a quarter of a second, the first time vividly, the second time faintly. Often it was seen a third time, and sometimes, but only with very great difficulty, even a fourth time. He gave to this phenomenon the name of recurrent vision; it may perhaps be more appropriately denominated the Young effect.

We have here a machine presented to the institution by Mr. Wimshurst, which is a giant in comparison with that used by Professor Young, and I hope by its means to be able to show the effect to everyone present who will give a little attention. Look in the direction of some object which is exposed to the light of the discharge; the object will be seen for an instant at the moment when the spark passes and you hear the crack, and after a dark interval of about one-fifth of a second it will make another brief appearance. Some of you may perhaps see even a second recurrent image. Under certain conditions I myself have observed no less than six reappearances of an object which was illuminated by a single discharge.

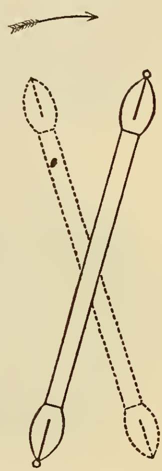

FIG. 1.

Twelve years ago I called attention to a very different method of exhibiting a recurrent image. The apparatus used for the purpose consists of a vacuum tube mounted in the usual way upon a horizontal axis capable of rotation. When the tube is illuminated by a rapid succession of discharges from an induction coil, and is made to rotate very slowly (at the rate of about one turn in two or three seconds) a very curious phenomenon may be noticed. At a distance of a few degrees behind the tube, and separated from it by a clear interval of darkness, comes a ghost. This ghost is in form an exact reproduction of the tube; it is very clearly defined, and though its apparent luminosity is feeble, it can no doubt be easily seen by most of you. The varied colors of the original are, however, absent, the whole of the phantom tube being of a uniform bluish or violet tint. If the rotation is suddenly stopped, the ghost still moves steadily on until it reaches the luminous tube, with which it coalesces and so disappears. (See fig. 1, where the recurrent image is indicated by dotted lines.)

I returned to the subject three or four years ago, with the primary object of ascertaining whether or not the Young effect was identical with one which had recently been discovered by Charpentier, and which will be referred to presently. A certain phenomenon which I had attributed to the Young effect was quoted by Charpentier as exemplifying his own newly observed one. I found, however, that the two effects, though both of an oscillatory character, were in fact quite distinct from one another. The results of my experiments in relation to this and other allied matters were embodied in a communication to the Royal Society.[1]

In investigating the influence of color upon the Young effect, two

[1] Proc. Roy. Soc., Vol. LVI, p. 132 (1894).

methods of experimenting were employed. In the first, colored light was obtained by passing white light through colored glasses; in the second and more perfect series of experiments, the pure colored light of the spectrum was used. Among other results, it was found that ceteris paribus the recurrent image was much stronger with green light than with any other, and that when the excitation was produced by pure red light, however intense, there was no recurrent image at all.

I intend to attempt a repetition of my first experiment before you. A metal disk with a small circular aperture near its edge is placed in the lantern, and its image projected upon the screen. When the disk is turned slowly the spot of light upon the screen goes round and round, and some of you may, perhaps, be able to see at once that the bright primary spot appears to be followed at a short distance by a much feebler spot of a violet color, which is the recurrent image of the first. It is essential to keep the direction of the eyes perfectly steady, which is not an easy thing to do without practice. (See fig. 2.) If now we place a green glass before the lens, the ghost will be at its best, and all of you should be able to see it, provided that you do not look at it. With an orange glass the ghost becomes less distinctly visible, and its color generally appears to be bluish-green instead of violet as before. When a red glass is substituted, the ghost completely disappears. If the speed of rotation is sufficiently high, the red spot is considerably elongated during its revolution, and its color ceases to be uniform, the rear portion assuming a light bluish-pink tinge. But however great the speed, no complete separation of the spot into red and pink portions can be effected, and no recurrent image is ever formed.

FIG. 2.

The spectrum method of observation can only be carried out on a small scale, and can not be exhibited to an audience. It, however, affords the best means of ascertaining how far the apparent color of the recurrent image depends upon that of the primary, a matter of some theoretical interest. I found that white light was followed by a violet recurrent image; after blue and green, when the image was brightest, its color was also violet; after yellow and orange, it appeared blue or greenish-blue. On the other hand, when a complete spectrum was caused to revolve upon the screen, the whole of its recurrent image from end to end appeared violet; there was no appearance of blue or greenish-blue at the less refrangible end. For this and other reasons it was concluded that the true color was in all cases really violet, the blue and greenish-blue apparently seen in conjunction with the much brighter yellow and orange of the primary being merely an illusory effect of contrast. (This contrast effect was illustrated by a lantern slide.) It seems likely, then, that the effect which has been spoken of as recurrent vision is due principally, if not entirely, to an action of the violet nerve fibers. It need hardly be pointed out that it represents only a transient phase of the well-known positive after-image, and it had even been observed in a vague and uncertain sort of way long before the date of Professor Young's experiment. Helmholtz, for example, mentions the case of a positive after-image which seemed to disappear and then to brighten up again; but he goes on to explain that the seeming disappearance was illusory.

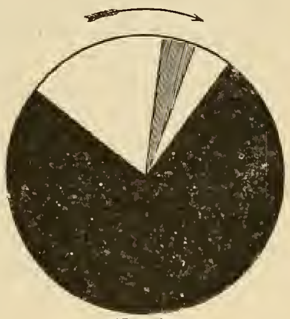

Fig. 3.

M. Charpentier, of Nancy, whose name I have already mentioned, was the first to notice and record a remarkable phenomenon which, in some form or other, must present itself many times daily to every person who is not blind, but which, until about six years ago, had been absolutely and universally ignored. The law which is associated with Charpentier's name is this: When darkness is followed by light, the stimulus which the retina at first receives, and which causes the sensation of luminosity, is succeeded by a brief period of insensibility, resulting in the sensation of momentary darkness. It appears that the dark period begins about one-sixtieth of a second after the light has first been admitted to the eye, and lasts for about an equal time. The whole alteration from light to darkness and back again to light is performed so rapidly that except under certain conditions, which, however, occur frequently enough, it can not be detected.

Fig. 4.

The apparatus which Charpentier employed for demonstrating and measuring the duration of this effect is very simple. It consists of a blackened disk with a white sector mounted upon an axis. When the disk is illuminated by sunlight and turned rather slowly, there appears upon the white sector close behind its leading edge a narrow but well-defined dark band. (See fig. 3.) The portion of the retina which is apparently occupied at any moment by the dark band is that upon which the light reflected by the leading edge of the white sector has fallen one-sixtieth of a second previously.

But no special apparatus is required to show the dark reaction; it is, as I have said, an exceedingly common phenomenon. In figure 4 an attempt has been made to illustrate what anyone may see if he simply moves his hands between his eyes and the sky or any strongly illuminated white surface. The hand appears to be followed by a dark outline separated from it by a bright interval. The same kind of thing happens in a more or less marked degree whenever a dark object moves across a bright background, or a bright object across a dark background.

In order to see the effect distinctly by Charpentier's original method the illumination must be strong. If, however, the arrangement is slightly varied, so that transmitted instead of reflected light is made use of, comparatively feeble illumination is sufficient. A very effective way is to turn a small metal disk having an open sector of about 60° in front of a sheet of ground or opal glass, behind which is a lamp. By an arrangement of this kind upon a larger scale the effect may easily be rendered visible to an audience. The eyes should not be allowed to follow the disk in its rotation, but should be directed steadily upon the center.

The acute and educated vision of Charpentier enabled him, even when working with his black and white disk, to detect the existence, under favorable conditions, of a second and sometimes a third dark band of greatly diminished intensity, though he remarks that the observation is a very difficult one. What is probably the same effect can, however, be shown quite easily in a different manner. If a disk with a very narrow radial slit, one-fiftieth of an inch or one-half millimeter wide, is caused to rotate at the rate of about one turn per second in front of a bright background, such as a sheet of ground glass with a lamp behind it, the moving slit assumes the appearance of a fan-shaped luminous patch, the brightness of which diminishes with the distance from the leading edge. And if the eyes are steadily fixed upon the center of the disk it will be noticed that this bright image is streaked with a number of dark radial bands, suggestive of the ribs or sticks of the fan. Near the circumference as many as four or five such dark streaks can be distinguished without difficulty; toward the center they are less conspicuous, owing to the overlapping of the successive images of the slit.[1] (The effect was demonstrated by means of a rotating disk in the lantern, and is roughly indicated in fig. 5.)

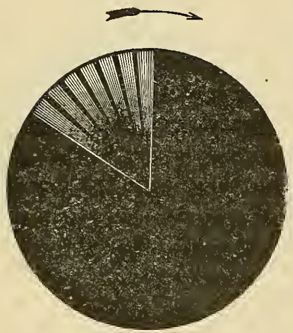

FIG. 5.

The dark reaction known as the Charpentier effect occurs at the beginning of a period of illumination. There is also a dark reaction of a very short duration at the end of a period of illumination. I should explain that, owing to what is called the proper light of the retina, ordinary darkness does not appear absolutely black. Even in a dark room on a dark night, with the eyes carefully covered, there is always some sensation of luminosity which would be sufficient to show up a really black image, if one could be produced. Now the darkness

[1] Proc. Roy. Soc., Vol. LVI, p. 142 (1894). A similar observation was described by Charpentier, Comptes Rendus, January, 1896.

which is experienced after the extinction of a light is for a small fraction of a second more intense than common darkness.

I believe that the first mention of this dark reaction occurs in the article which I contributed to Nature in 1885, in which it was stated that when the current was cut off from an illuminated vacuum tube "the luminous image was almost instantly replaced by a corresponding image which appeared to be intensely black upon a less dark background," and which was estimated to last from one-fourth to one-half of a second. "Abnormal darkness," it was added, "follows as a reaction after the luminosity."

In the Royal Society paper, to which I have before referred, the point is further discussed, and a method is described by which the stage of reaction may be easily exhibited and its duration approximately measured. If a translucent disk made of stout drawing paper and having an open sector is caused to rotate slowly in front of a luminous background, a narrow radial dark band like a streak of black paint appears upon the paper very near the edge which follows the open sector. From the space covered by this band when the disk was rotating at a known speed, the duration of the dark reaction was estimated to be about one-fiftieth of a second. (The experiment was shown and is illustrated in fig. 6.)

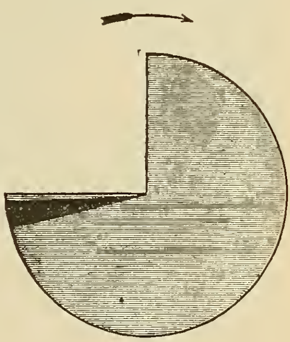

FIG. 6.

One more interesting point should be noticed in the train of visual phenomena which attend a period of illumination. The sensation of luminosity which is excited when light first strikes the eye is for about one-sixtieth of a second much more intense than it subsequently becomes. This is shown by the fact that the bright band intervening between the leading edge of the white sector of a Charpentier disk and the dark band appears to be much more strongly illuminated than any other portion of the sector.

I propose now to say a few words about a curious phenomenon of vision which occupied my attention toward the end of last year.[1]

Rather more than two years ago Mr. C. E. Benham brought out a pretty little toy which he called the artificial spectrum top. It consists of a cardboard disk, one half of which is painted black, while on the other half are drawn four successive groups of concentric black lines at different distances from the center. When the disk rotates rather slowly each group of black lines generally appears to assume a different color, the nature of which depends upon the speed of the rotation and the intensity and quality of the light. Under the best conditions the inner and outer groups of lines become bright red and dark blue; at the same time the intermediate groups also appear tinted, but the hues

[1] Proc. Roy. Soc., Vol. LX, p. 370 (1896).

which they assume are rather uncertain and difficult to specify. By far the most striking of the colors exhibited by the top is the red, and next to that the blue. This latter, however, is sometimes described as bluish green. (The top was exhibited as a lantern slide.)

My recent experiments seem to indicate pretty clearly the cause of the remarkably bright red color, and also that of the blue. The more feeble tints of the two intermediate groups of lines perhaps result from similar causes in a modified form, but these I have not yet investigated.

In the red color we have another striking example of an exceedingly common phenomenon which is habitually disregarded; indeed, I can find no record of its ever having been noticed at all. The fact is, that whenever a bright image is suddenly formed upon the retina after a period of comparative darkness, this image appears for a short time to be surrounded by a narrow colored border, the color under ordinary conditions of illumination being red. If the light is very strong the transient border is greenish blue. Sometimes both red and blue borders appear together, the blue being inside the red.[1] The color generally seen is, however, red, and it is most conspicuous with good lamplight.

This observation was first made in the following manner: A blackened zinc plate with a small round hole in it is fixed over a larger hole in a wooden board; the hole in the zinc is covered with a piece of thin white writing paper. Thus we are furnished with a sharply defined translucent disk which is surrounded by a perfectly opaque substance. An arrangement is made for covering the translucent disk with a shutter which can be opened very rapidly by means of a strong spring. If this apparatus is held between the eyes and a lamp, and the translucent disc is suddenly disclosed by working the shutter, the disk appears for a short time to be surrounded by a narrow red border. The width of the border is perhaps one twenty-fifth of an inch, or 1 millimeter, and the appearance lasts for something like one-tenth of a second. Most people are at first quite unable to recognize this effect, the difficulty being not to see it, but to know that one sees it. Those who have been accustomed to visual observations generally perceive it without any difficulty when they know what to look for, and no doubt it would be quite evident to a baby a few weeks old, which had not advanced very far in the education of its eyes.

The observation is made rather less difficult by a further device. If the disk is divided into two parts by an opaque strip across the middle, it is clear that each half disk will have its red border, and, if the strip is made sufficiently narrow, the red borders along its edges will meet, or perhaps overlap, and the whole strip will, for a moment after the shutter is opened, appear red. A disk was prepared by gumming across the paper a strip of tin foil about one-thirtieth of an inch wide.

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[1] I have recently shown that the greenish-blue border is simply the "negative after-image" of the red one. April 24.

The effect produced when such a disc is exposed is indicated in figure 7, the red color being represented by shading.

A simpler apparatus is, however, quite sufficient for showing the effect,[1] and with practice one can even acquire the power of seeing it without any artificial aid at all. I have many times noticed flashes of red upon the black letters of a book that I was reading, or upon the edges of the page. Bright metallic or polished objects often show it when they pass across the field of vision in consequence of a movement of the eyes, and it was an accidental observation of this kind which suggested the following easy way of exhibiting the effect experimentally:

An electric lamp was fixed behind a round hole in a sheet of metal which was attached to a board. The hole was covered with two or three thicknesses of writing paper, making a bright disk of nearly uniform luminosity. When this was moved rather quickly, either backward or forward, or round and round in a small circle, the edges of the streaks of light thus formed appeared to be bordered with red.

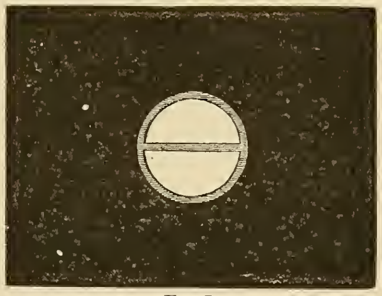

FIG. 7.

If this experiment is performed with a strong light, the hole becomes bordered with greenish blue instead of red. With an intermediate degree of illumination both blue and red may be seen together, the blue being inside the red.

Most of the effects that have so far been described were produced by transmitted light, but reflected light will show them equally well. If you place a printed book before you near a good lamp and interpose a dark screen before your eyes, then, when the screen is suddenly withdrawn, the printed letters will for a moment appear red, quickly changing to black. Some practice is required before this observation can be made satisfactorily, but by a simple device it is possible to obliterate the image of the letters before the redness has had time to disappear; the color then becomes quite easily perceptible. Hold two screens together side by side, a black one and a white one, in such a manner that there is a triangular opening left between them. In the first place let the black screen cover the printing, then quickly move the screens sideways so that the printed letters may be for a moment exposed to view through the gap, stopping the movement as soon as the page is covered by the white screen. During the brief glimpse that will be had of the black letters while they are beneath the gap, they will, if the illumination is suitable, appear to be bright red.

We may go a step further. Cut out a disk of white cardboard, divide

[1] See Nature, Vol. LV, p. 367 (February 18, 1897).

it into two equal parts by a straight line through the center, and paint one half black. At the junction of the black and white portions cut out a gap which may conveniently be of the form of a sector of about 45°. (See fig. 8.) Stick a long pin through the center and hold the arrangement by the pointed end of the pin a few inches above a printed page near a good light. Make the disk spin at the rate of about five or six turns a second by striking the edge with the finger. As before, the letters, when seen through the gap, will appear red, and persistence will render the repeated impressions almost continuous. Care must be taken that the disk does not cast a shadow upon the printing, and that the intensity of the illumination is properly adjusted. I have here several rather more elaborate contrivances for making disks rotate.

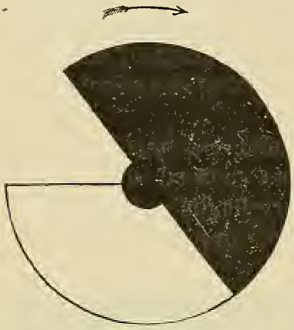

FIG. 8.

In none of these experiments does an extended black surface ever appear red, but only black dots or lines, which may, of course, have the form of letters. And the lines must not be too thick; if their thickness is much more than one twenty-fifth of an inch, or 1 millimeter, the lines, as seen by an observer at a distance of 2 or 3 feet, do not become red throughout, but only along their edges. The red appearance is, in fact, not due to the black lines themselves at all; these serve merely as a background for showing up the red border which fringes externally the white portions of the paper, and the width of this border does not exceed about one-fifth of a degree.

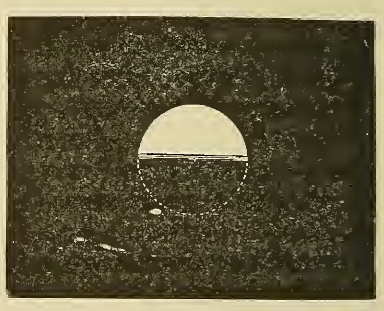

FIG. 9.

(By means of a large rotating disk some designs in black lines and letters were made to appear red, the effect being visible in all parts of the theater.)

When the disk is turned in the opposite direction, the black lines appear at first sight to become dark blue. Attentive observation, however, shows that the apparently blue tint is not formed upon the lines themselves, as the red tint was, but upon the white ground just outside them. This introduces to our notice another border phenomenon which seems to present itself when a dark patch is suddenly formed on a bright ground, for that is essentially what takes place when the disc is turned the reverse way. I made some attempts to obtain more direct evidence that such a dark patch appeared for a moment to have a blue border, and after some trouble succeeded in doing so.

A circular aperture was cut in a wooded board and covered with white paper; a lamp was placed behind the board, and thus a bright disc was obtained, as in the former experiment. An arrangement was prepared by means of which one-half of this bright disk could be suddenly covered by a metal shutter, and it was found that when this was done a narrow blue band appeared on the bright ground just beyond and adjoining the edge of the shutter when it had come to rest. The blue band lasted for about one-tenth of a second, and it seemed to disappear by retreating into the black edge of the shutter. An attempt has been made to illustrate it in figure 9, where the shaded band indicates the blue border.

We have then to account, if possible, for the two facts that in the formation of these transient borders the red sensation occurs in a portion of the retina which has not been exposed to the direct action of light, while the blue occurs in a portion which is exposed to unchanged illumination. Accepting the Young-Helmholtz theory of color vision, the effects must, I think, be attributed to a sympathetic affection of the red nerve fibers. When the various nerve fibers occupying a limited portion of the retina are suddenly stimulated by white or yellow light of moderate intensity, the immediately surrounding red nerve fibers are for a short period excited sympathetically, while the violet and green fibers are not so excited, or in a much less degree. And again, when light is suddenly cut off from a patch in a bright field, there occurs an insensitive reaction in the red fibers just outside the darkened patch, in virtue of which they cease for a moment to respond to the luminous stimulous; the green and violet fibers, by continuing to respond uninterruptedly, give rise to the sensation of a blue border.

Whether or not the hypothesis which I have suggested is correct in all its details, it is, I think, sufficiently obvious that the red and blue colors of Benham's top are due to exactly the same causes as the colors observed in my own experiments, for the essential conditions are the same in both cases.

I have mentioned only a few among many curious phenomena which have presented themselves in the course of my investigation. It is not improbable that a careful study of the subjective effects produced by intermittent illumination would lead to results tending to clear up many doubtful points in the theory of color vision.

PROGRESS IN COLOR PHOTOGRAPHY.[1]

By G. H. NIEWENGLOWSKI.

Color photography is the order of the day. Within the last year there have been numerous exhibitions of color photographs, one of the most notable of which is that recently established on the boulevard des Italiens by the brothers Lumière of Lyons. The time is therefore appropriate to give a brief review and comparison of the various processes of photographic reproduction in colors which have thus far been proposed.

Methods of color photography may be either direct or indirect. The first class contains those which give at a single direct operation a proof in colors.

Many of the direct processes are variations of the method called the destruction of colors, originated by Charles Cros, and described by him as follows in the Moniteur de la Photographie (1881, p. 67) under the title of direct polychromy:

"The fundamental experiment upon which polychromy is founded is this:

"A glass plate is coated first with collodion dyed red with carthamine. To this is added a second coat of gelatine dyed blue with phyllocyanine, and finally a coat of collodion dyed yellow with tumeric.

"Upon subjecting this plate to an image formed in green, yellow, and orange light the following occurs:

"The green light produces no appreciable effect upon the yellow and blue coatings, but is absorbed in the red coating and decolorizes the carthamine. Thus there remains only yellow and blue at this point in the coatings of the glass plate, and these two colors superposed produce green. Hence the green light leaves a green trace.

"Similarly, violet light destroys the yellow, and leaving blue and red superposed gives a violet trace, while the orange light, destroying the blue, leaves only yellow and red, which superposed give orange.

"Finally white light destroys all these pigments and leaves only the colorless plate, while in the absence of light none of the pigments are affected and there remains the neutral tint formed by the superposition of all three.

"Thus the resulting effect is a direct positive transparency reproducing the original colors. But this positive is not durable, for under the action of light it disappears."

[1] Translated from Cosmos, Paris, 1899. New series No. 741, pp. 433–437.

In June, 1895, Otto Wiener published in the Annalen der Chemie und Physik a memoir entitled "Color photography and mechanical color adaptation in nature," which has been discussed by Bernard Brunhes in the Revue Générale des Sciences, 1895. In this memoir Wiener shows that the reproduction of the spectrum as obtained by Seebeck, and Poitevin's process of color photography upon paper coated with the subchloride of silver, were both based upon the same principle as the direct polychromy of Charles Cros, though Wiener does not cite Cros and seems to have overlooked his work. Wiener gives the name of color-sensitive films to coatings capable of taking on the color of the light incident upon them.

In the process of Poitevin the color-sensitive substance, according to Wiener, is a mixture of the chloride and subchloride of silver, capable of appearing in various colors, and given by Carey Lea the name of "color salt."

By the aid of researches described in the memoirs of Wiener, he concludes that the ideal color-sensitive substance would be a black absorbent mixture containing at least three different-colored substances, each of which should absorb all the colors of the spectrum except one and be destroyed by the colors which it absorbed. A single-colored light falling upon such a substance would leave intact only the color the same as its own. We have already seen, in quoting from Charles Cros, what would be the effect of a light of mixed colors on such a substance.

This kind of color adaptation by means of a color-sensitive substance is not infrequently met with among animals. Certain species take on the color of their surroundings. Thus *Danais chrysippus*, green in nature, becomes white, red, orange, or black when brought up in boxes constructed of white, red, orange, or black paper.

Immediately after the publication of the interesting research of Wiener, Emile Vallot devoted himself to the task of obtaining a good color-sensitive coating. He recommends a mixture in equal parts of the following three solutions:

	Cubic centimeters.
Alcohol	50
Aniline purple	0.20
Alcohol	50
Tumeric	0.20
Alcohol	50
Victoria blue	0.20

Paper floated for several minutes upon this bath and dried in darkness is dyed black. If placed in a colored image cast by full sunlight, it gives a good photographic reproduction in the proper colors. Unfortunately two or three days' exposure are necessary, and the yellow is not altogether satisfactory. For the red, the aniline purple may be replaced advantageously with safranine.

A. and L. Lumière have obtained a more sensitive paper by employing cyanine for the blue and quinoleine for the red.

Two principal difficulties are encountered in this process. The first consists in the discovery of colored substances which not only have the proper colors (corresponding respectively to the three fundamental colors), but which have besides the same laws of sensitiveness. A second difficulty, as yet unsurmounted, is found in fixing the colors when obtained. The Lumières have, however, made some progress in fixing, by means of metallic salts which form insoluble compounds with the colors employed. Nevertheless it is very hard to avoid modifying the tint in this way. Commandant Colson has made tentative experiments in fixing color photographs made by Poitevin's process, and utilizes a property of dry ink to desensitize the color-sensitive substances.

To sum up the matter, it may be said that these processes appear unlikely to give more than a partial solution of the problem.

Color photographs were obtained in 1848 by Edmond Becquerel by another species of the direct process, and his researches have been repeated and completed by Niepce of St. Victor. As a sensitive surface Becquerel employed a silver plate superficially chlorinized, either by means of electrolysis or by some strictly chemical process. Becquerel's colored images could not be fixed, and the theory of their formation was, in his time, little understood.

To Prof. Gabriel Lippmann belongs the honor of showing in 1891 the true theory of the phenomenon, and of finding out why the colors could not be fixed, and finally of giving an ingenious solution of the problem of photography in colors, which has come to world-wide fame. Since it is based on the principle of interference, this discovery forms a beautiful confirmation of the undulatory theory of light. It will be recalled that in Lippman's as in Becquerel's process the image is formed by a series of layers of silver separated by distances varying with the colors. If hyposulphite of soda be used to fix colored images of the Becquerel type, it dissolves the intervening chloride of silver which supports this system of layers, so that the whole structure crumbles and the colors are destroyed.

In Lippmann's process this difficulty is avoided, because the sensitive salt is imprisoned in a transparent mass of albumin, gelatin, or collodion, upon which the hyposulphite has no action. Only the bromide of silver not modified by the light is dissolved, and the substratum forms a solid foundation which maintains invariable the distance separating the layers of silver from one another.

In reality, as Wiener has shown in the memoir already cited, though these interference colors predominate in the Becquerel images, yet there are also present body colors, due, as in the direct processes already mentioned, to the modification of color-sensitive substances.

Since the communication by Lippmann to the Académie des Sciences in February, 1891, many photographers have attempted to repeat his experiments. But, despite numerous researches undertaken to explain the want of success, it appears that there are only two or three dozen good interference color photographs in existence. The delicacy of the lamellar structure is so great that a very slight variation in the conditions of the experiment suffices to spoil its result. Thus even the brothers Lumière, who are certainly the most conscientious students, from a practical standpoint, of interferential color photography, have not been able to obtain identical results even "when working with weights of substance as nearly equal as could be determined with the very best balances, when the successive operations were separated by the same intervals of time, and when the experiments were carried on under conditions as nearly identical as possible as regards the temperature, the degree of moisture of the air, etc."[1]

Lippmann's method—although the one giving the most beautiful, complete and accurate results—has still another inconvenience. It is impossible to multiply copies, so that it is necessary to make as many exposures in the camera as there are pictures desired, just as in the old daguerreotype. But perhaps this is not wholly an objectionable feature of this process of Lippmann's.

For our part we incline to this view of the matter, and quite agree with Louis Ducos du Hauron.[2]

"If multiplicity has its merits," he remarks, "so also does rarity. If the happy possessor of a painting signed by a great artist were asked if he would be willing to have numerous copies of his picture sent abroad throughout the world, his response might be expected in advance to be vigorous in the negative. To be sure the Almighty made the rose, called the queen of flowers, abundant, but he has at the same time set the diamond in an enchanting solitude."

Indirect processes of color photography, properly so called, are derived from the method indicated in 1869 by Charles Cros and Louis Ducos du Hauron, who independently conceived the same idea. Many processes noised abroad from time to time are only variations of that invented by these our two compatriots, whose works seem now to be ignored, voluntarily or otherwise, by many.[3]

Indirect photography in colors is based upon the fact that the mixture in variable proportions of three colors suitably chosen, and called fundamental colors (red, yellow, and blue), enables the reproduction of all the shades met with in nature.

The principle of the method is thus defined by Ducos du Hauron:

"If we decompose into three distinct images—one red, one yellow, and one blue—the combination images presented by nature, and if each one

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[1] A and L. Lumière. Photography in Colors, its Methods and its Results. Communication to the French Society of Photography, January 3, 1896.

[2] Ducos du Hauron, La Triplice Photographique des Couleurs et l'Imprimerie.

[3] We especially recommend to the attention of those of our readers who desire to know the various researches of Louis Ducos du Hauron the work of his brother Alcide Ducos du Hauron: La Triplice Photographie des Couleurs de l'Imprimerie, published by Gauthier-Villars.

of these three pictures is reduced to a separate photograph and reproduced in the special color, it only requires to blend again into one the three colored reproductions thus made in order to obtain an exact representation of the original as regards both color and form."

When the three clichés representing in analysis the colors of the original have been obtained, their synthesis can be effected by one of two different methods.

1. *By addition of lights.*—Ordinary positives of the three clichés are produced and illuminated, respectively, with blue, yellow, and red light, each positive being illuminated by the same light which passed the screen in producing the corresponding negative. When these three separately illuminated positives are superposed, either by means of a projection lantern (thus forming a real image) or by means of chromoscopes (virtual images), there is obtained a very faithful reproduction of the colors of the original. Prof. G. Lippmann has proposed a very ingenious device to make both the analysis and synthesis of the colors with the same apparatus. He employs the principle of reversibility of path of the rays traversing a lens. Three small objective lenses are mounted on a support in a camera and provided with three colored screens. In the foci of the lenses are placed plates sensitive to the colors transmitted, respectively, by the corresponding screens. From the three negatives thus obtained are reproduced positives on glass, which are placed in the positions first occupied by the negatives, and illuminated by the beam of a projection lantern. In this manner a colored image of the original is projected upon a white screen. This image can be magnified or diminished at pleasure by placing a fourth lens of suitable curvature in the path of the beam.

2. *By absorption of light.*—Procedures for synthesis of this kind are very numerous. They admit of multiplication of copies. The carbon process was employed first by Louis Ducos du Hauron. Charles Cros communicated in 1881 to M. Carpentier, of the Académie des Sciences, a process of reproduction analogous to hydrotypy, based upon the employment of coatings of albuminated collodion containing from 2 to 3 per cent of bromide of cadmium sensitized with ammonium bichromate. This process is analogous to that employed by the brothers Lumière in producing their beautiful color photographs. A skillful photographer, George Richard, has also proposed a very ingenious method. Positives from the three clichés are first produced on glass. Then by means of a series of chemical reactions the reduced silver which forms the image is transformed either into a mordant capable of fixing the analine colors or into a salt capable of reacting upon analine to produce colors upon the plate. The three positives are then superposed to give color photographs.

These polychrome proofs have to be viewed as transparencies. It is, to be sure, possible to transfer the films to paper, and thus to have photographs upon paper, but the results thus obtained are far less satisfactory.

One of the greatest advantages of the indirect methods is that they permit of reproductions by photomechanical processes, and thus lend themselves to illustrative purposes. The colors may be either superposed or juxtaposed. Superposition, however, requires at least two transparent colored inks. Hence, the mixture of colors is generally produced by juxtaposition of pigments. This is done sometimes in photocollography by producing grained images; but more frequently by phototypogravure, which has the great advantage of being suited to the production of numerous copies.

The three-color process of mechanical polychrome illustration was for a long time made use of in England and America. Of late, however, a number of French firms have had excellent success in the form of illustration.

A great objection to indirect color photography is that it requires three negatives, which consume time for their production. The red, especially, requires a very long exposure. Nevertheless, this process is much employed for landscapes, and not long since M. Montpillard presented to the French Photographic Society a very excellent colored typophotograph representing a landscape photographed by him from nature and engraved by M. Prieur.

There has been much effort to simplify the process. One of the first methods proposed was to use a camera provided with mirrors, so that the three exposures could go on simultaneously. But the images thus obtained are by no means equal to those produced when the apparatus is used in the ordinary way with three separate exposures. It has been proposed to use three separate lenses, but this, of course, accentuates the same defect. It is very difficult to have three objectives which will give three images precisely identical.

Another device, proposed by John Joly, of Dublin, about three years ago, but really a re-edition of a procedure published in 1869 by Louis Ducos du Hauron, consists in obtaining the three negatives upon a single sensitive surface. A glass plate is ruled with fine parallel lines colored in rotation with the three fundamental colors in transparent pigments. This prepared plate is superposed on the sensitive surface, and thus is produced in close juxtaposition a combination of the three negatives corresponding to the three primary colors. A positive transparency of this negative is projected upon a screen through a color grating exactly like that first used, and the colors of the original are thereby closely reproduced. Louis Ducos du Hauron applied this same process to photomechanical reproduction by printing a black image upon a paper ruled like the screen in red, blue, and yellow.

The colors of the original are fairly rendered in this way. However, it is easy to see that if the original presented a considerable blue space this would be represented in the picture by a space one-third blue and two-thirds black. Besides this, the objects appear cut up into a sort of grating, and the effect is rather disagreeable.

Of all the processes of color photography that have thus far been proposed only the elegant interferential method of Lippmann reproduces the colors of the original with absolute fidelity. The indirect method by three negatives in colors, proposed by Charles Cros and Ducos du Hauron, seems to give only an approximate solution of the problem. But the approximation may be practically sufficient, as is shown by the fine transparencies of the Lumière brothers. This method has, moreover, the advantage that it lends itself to industrial reproductions, as may be seen in the illustrations of M. Prieur.

It seems, then, that from the practical and industrial point of view a brilliant future is reserved for the ingenius three-color method first clearly indicated by the Frenchmen, Charles Cros and Louis Ducos du Hauron.

THE DEVELOPMENT OF ELECTRICAL SCIENCE.[1]

By THOMAS GRAY.

In a brief discourse on the development of electrical science little time can be given to the early history of the subject. This part is more or less familiar to all the members of the academy, and hence it may be passed over by only such brief reference as may serve to recall to mind the more important of the early discoveries. The early Greeks have recorded some elementary phenomena now known to be electric, and it is probable that such knowledge was not uncommon, though little noticed. It is only in comparatively recent times that scientific research has taken the place of superstition and attempts have been made to classify and find reasons for the existence of all natural phenomena.

Beginning with the seventeenth century, probably the first investigator worthy of notice in this subject was Gilbert, of Colchester, who published his work entitled De Magnete in 1600. Gilbert made systematic experiments and showed that the property of attracting light bodies could be given to a large number of substances by friction. He also showed that the success of the experiment depended largely upon the dryness of the body. These experiments gave rise to the classification of substances as electrics and nonelectrics. The true significance of Gilbert's observations as to the effect of moisture was not appreciated for a long time. Gilbert's list of electrics was added to by a number of other observers, prominent among whom were Boyle and Newton. The fact that light and sound accompany electric excitation was called attention to by Otto von Guericke, who also showed that a light body after being brought into contact with an electrified body was repelled by it.

Coming now to the eighteenth century, we find Hawkesbee in 1707 and Wall in 1708 speculating on the similarity of the electric spark and lightning. Then comes one of the most prominent experimenters of this century—Stephen Gray—who began to publish in 1720, and who in 1729 found that certain substances would not convey the charge

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[1]Address of the president delivered before the annual meeting of the Indiana Academy of Sciences on December 29, 1897. Printed in Science March 18 and 25, 1898.

of an electrified body to a distance. These experiments were the first to introduce the distinction between conductors and non conductors, and, of course, very soon served to explain the reason why certain substances could not be electrified by friction when held in the hand. Gray also made the important discovery that the charge of an electrified body is proportional to its surface, and this was afterwards confirmed by the experiments of Le Monnier. Many of Gray's experiments were repeated and extended by Du Fay, who found that all bodies could be electrified by friction if they were held by an insulating substance. Then came the improvements of the electric machine by Boze and Winckler; the firing of inflammatory substances, such as alcohol, by means of the electric spark by Ludolph, Gordon, Miles, Franklin, and others. About this time (1745) the properties of the Leyden jar were discovered by Kleist, Cuneus, and Muschenbroeck, and a few years later it was given practically its present form by Sir William Watson. Then follows one of the periods of exceptional activity in electrical research. A party of the Royal Society, with Watson as chief operator, made a series of experiments having for their object the determination of the distance to which electrical excitation could be conveyed and the time it takes in transit. They found, among other things, that several persons at a distance apart might feel the electric shock if they formed part of a circuit between the electrified body and a conductor, such as the earth; also, that the earth could be used to complete the circuit in Leyden jar discharges. They concluded that when two observers connected by a conductor, and at, say, 2 miles apart, obtained a shock by one touching the inside coating of a Leyden jar and the other the earth, the electric circuit was 4 miles long; that is, the earth acted as a return conductor. They also concluded that the transmission was practically instantaneous. Watson had ideas as to electric fluids similar to those which were afterwards systematically worked out by Franklin. A great many curious and interesting experiments were made about this time, as, for example, the influence of electrification on the flow of water through capillary tubes as discovered by Boyle, the experiments of Mowbray on the effect of electrification on vegetation, and those of the Abbe Menon on the loss of weight of animals when they were kept electrified for a considerable time.

The effect of electrification on the flow of water has received considerable attention from eminent authorities in recent years, and the effect of electrification on the growth and composition of vegetables is at present attracting attention in the form of systematic investigation.

The contributions of Franklin are by far the most important which mark the middle portion of the eighteenth century. Franklin's experiments were begun about the middle of the year 1747, and seem to have been inspired by the receipt of a Leyden jar from a friend, William Collinson, of London. He propounded the theory of positive and negative fluids, which has lately, in a modified form, been brought so prominently into notice again by the writings of Lodge, and he made an investigation of the principle of the Leyden jar; but the most important of his researches relate to the identification of electricity and lightning. The probable identity of the two phenomena had been hinted at, as we have seen, by several observers, but Franklin went systematically to work to test the hypothesis. Under date of November 7, 1749, the following passage is found in his notebook: "Electric fluid agrees with lightning in these particulars: (1) Giving light; (2) color of the light; (3) crooked direction; (4) swift motion; (5) being conducted by metals; (6) crack or noise in exploding; (7) subsisting in water or ice; (8) rending bodies in passing through; (9) destroying animals; (10) melting metals; (11) firing inflammable substances; (12) sulphurous smell. The electric fluid is attracted by points; we do not know whether this property is in lightning. But since they agree in all the particulars wherein we can already compare them, is it not probable that they agree likewise in this? Let the experiment be made." The hypothesis was elaborated and sent to his friend Collinson, who communicated it to the Royal Society. This society rather ridiculed Franklin's ideas at first, but his paper was published in London and also in France, and attracted considerable attention.

The experiment was first made in France by M. d'Alibard, at Marli, on May 10, 1752, and it was repeated shortly afterwards by M. de Lor in Paris. The results of what were called the Philadelphia experiments were communicated to the Royal Society and caused quite a stir in scientific circles. It is right to say with regard to the Royal Society that Franklin's claims to scientific recognition were championed by Sir William Watson and were fully indorsed by the society by his election to a fellowship and the award of the Copley medal, together with the free donation of the society's Transactions during his life.

Franklin's own experiments with kites are well known, as is also the method of protecting buildings from lightning which was introduced by him, and is still very widely used, although it has been greatly abused by the lightning-rod man.

During the next decade Canton discovered the now commonly known difference between vitreous and resinous electricity. Beccaria experimented on the conducting power of water. Symmer made a number of interesting experiments on the electrification of different kinds of fabrics by friction and propounded a theory of two electric fluids. Contemporaneous with these were a number of other experimenters who added to the stock of knowledge of this class of phenomena.

The experiments of Æpinus and others on the pyroelectric properties of tourmaline now began to attract attention. The experiments of the Abbé Haüy are perhaps the most important in this connection at this stage of the subject. He found the polar properties of the crystal and showed that similar properties were possessed by a number of other crystals. Æpinus made experiments in other branches of electricity, but he is chiefly noted for his ingenious single-fluid theory of electricity.

Between the years 1770 and 1780 the electrical organs of the torpedo were one of the principal topics of discussion. The experiments of Walsh and Ingenhousz were the first to definitely settle the character of the peculiar power of the fish.

The experiments of Cavendish belong to this period and were remarkable as being quantitative in their character. Considering the means at his command, the measurements made by this experimenter of the relative conducting powers of various substances must always excite admiration. Cavendish also proved the composition of water by causing different proportions of oxygen and hydrogen to unite by means of the electric spark.

We now come to the classical experiments of Coulomb, who established the law of the variation of the electric force with distance to be that of the inverse square, a law which had previously been inferred from experiments on spheres by Dr. Robinson, who, however, did not publish his results. Coulomb made an elaborate series of experiments on the distribution of electricity over charged conductors as influenced by shape and the proximity of other charged bodies. His theoretical and experimental work formed the basis of the mathematical theory as developed shortly afterwards by Laplace, Biot, and Poisson, the work of the latter being particularly important.

Toward the end of the eighteenth century were made the important researches of Laplace, Lavoisier, and Volta, and of Sausure on the electricity produced by evaporation and combustion. This is a subject destined to figure prominently again in the future, and in its rise there is in all probability involved the rapid decline in the importance of the steam engine. I should not be surprised if many of those present should live to see the steam engine practically a thing of the past.

To the eighteenth century, also, we must assign the discovery of galvanic electricity, as the famous frog experiments were made in 1790. Practically no development was made, however, until Volta's work attracted the attention of the scientific world.

At the beginning of the nineteenth century, then, we find the subjects of greatest interest were the discoveries of Volta and the invention of the voltaic pile. There followed almost immediately the discovery by Nicholson and Carlisle of the decomposition of water by the voltaic current. This discovery was followed a few years later by those of Sir Humphry Davy on the decomposition of the alkalies and the separation of metallic sodium and potassium. Thus the subject of electrolysis was fairly launched, and what it has grown to be we will see later.

Can there be some interrelation between electricity and magnetism? was now the query. The first positive answer seems to have been given by Romagnesi in a work published in 1805, but little or no notice appears to have been taken of this. Certainly no progress was made in the subject till 1820, when Oersted made his famous experiment before his class. By that experiment he proved that a wire carrying an electric current will, when properly placed, deflect a magnetic needle. The subject was almost immediately taken up by Ampère, and in a few months many of the important consequences which Oersted's discovery involved were developed. Ampère's work on the action of currents on currents and on magnets is classical and is still treated as part of the fundamental basis for the theory of electrodynamics. An account of his work may therefore be found in almost any of the numerous text-books on electricity. The conclusions reached by Ampère were confirmed by Weber by a series of much more refined experiments. To Weber also we owe improvements in galvanometers. The same year marks the discovery by Arago that a current can not only deflect a magnet, but that it is capable of producing one by magnetizing steel needles.

The further discovery was made four years later by Sturgeon that soft iron, although incapable of making a strong permanent magnet, is yet much more susceptible than steel to temporary magnetization by the electric current. Arago also made about this time the important discovery that if a needle be suspended above a copper disc and the disc rotated the needle will be dragged round with the disc. This was not explained for some years, but seems to be the first discovery of induced currents.

These experiments mark the discovery of electro-magnetism, and began one of the most important eras in electrical discovery, the work which has been participated in by many eminent authorities. Among the many advances may be mentioned the experiments of Henry on the relative effects of different windings on the strength of an electromagnet. He deduced the fact that the magnetizing action might be increased either by increasing the number of windings, the current remaining the same, or by increasing the current, the winding remaining the same. He pointed out the application of this to intensity and quantity arrangements of the battery, and also the importance of the intensity winding for the transmission of magnetizing power to a distance, as in telegraphy. The increased effect due to increasing the number of windings on the coil of a galvanoscope had been previously pointed out by Schweigger, and the discovery is embodied in Schweigger's galvanoscope.

In 1821 Faraday began his researches and many inportant discoveries were made by him. The main guiding idea in Faraday's work was the possibility of obtaining electricity from magnetism and in general the discovery of the interrelation between the two. In this connection Arago's discovery of the rotation of a copper disc by the rotation of a magnet above it is of great importance, because, among other things, Faraday set himself to explain this. The result was the discovery of the commutatorless dynamo, or Faraday disk. In view of modern developments, probably the most important of Faraday's discoveries was that of the production of a current in a circuit when a current is either established or varied in strength in an adjacent circuit. This was followed by the discovery that relative motion of two circuits, one of which carried a current, produced a current in the other, and that the motion of a magnet in the neighborhood of a circuit produced a current in the circuit. Another important discovery by Faraday was that of the quantitative laws which govern electrolytic decomposition, thus giving us our electro-chemical equivalents.

At this time Lenz was led by experiment to the discovery of his celebrated law of induction, namely, that the current produced always in turn produces forces tending to oppose the change. For example, if a current be induced in a coil by bringing a magnet toward it the mutual action between the magnet and the current is to oppose the magnet's approach. This is important when looked at from the point of view of the conservation of energy or as an argument against perpetual motion. Lenz's law is, of course, when the actions are properly understood, a consequence of Newton's third law of motion.

Discoveries similar to those of Faraday as to induced currents were made almost simultaneously by Henry in this country. We have in the discoveries of Faraday and Henry the fundamental information required for nearly the whole of our recent developments in dynamo-electric generators and electric motors, but it was reserved for the next generation to develop them. This development we owe in no small degree to the splendid exposition of Faraday's discoveries and their consequences contained in Maxwell's book on electricity and magnetism.

Going back for a moment to 1822, we have to notice another important discovery, namely, the thermoelectric couple by Seebeck. There followed almost immediately the important experiment of Cumming, who showed that the thermoelectric order of the metals is not the same at all temperatures.

The next important discovery in thermoelectricity was that of Peltier, of the heat generated at the junction of two metals when a current is forced across it against the electro-motive force of the junction. In later years we have the classic researches of Thomson (Kelvin), who added thermoelectric convection and the specific heat of electricity and gave the thermoelectric diagram method of representing results. This method was afterwards used and extended by Tait, who added a good deal to our knowledge of thermoelectric data. Among the large number of others who have worked in this field we may mention Becquerel, Magnus, Matthieson, Leroux, and Avenarius. Thermoelectric batteries of considerable power have been made by Clamond and others.

In 1827 the celebrated law giving the relation between electro-motive force resistance and current was published by Ohm in a paper on the mathematical theory of the galvanic circuit. The theory has been sometimes criticised, but there seems to be absolute certainty that the law is almost exact, and it has proved of the greatest importance in the further development of the subject of electric measurements.

The subject had about the middle of the century reached a stage in which it was possible to develop almost completely the mathematical theory as we now have it. Most of the work since Faraday's time has been directed toward quantitative measurements and the furnishing of exact data to answer questions as to how much in various cases. F. E. Neumann discovered what he called the potential function (now called the coefficient of self and mutual induction) of one current on another and on itself, and succeeded in giving a theory of induction which was in accordance with the experimental laws. The laws were afterwards experimentally verified by Weber. In 1849 the experiments of Kirchoff on the absolute value of the current induced in one circuit by another, and in the same year Edlund's experiments on self and mutual induction are important. In 1851 Helmholtz gave a mathematical theory of this part of the subject, which he supplemented with an experimental verification.

One of the most important of the series of experiments made by Henry was on the oscillatory character of the discharge from a Leyden jar. This he discovered from the effect of the discharge on a steel needle surrounded by a coil, through which the current was made to pass. The results of these experiments were communicated to the American Association for the Advancement of Science in 1850, but he knew of the effect much earlier, certainly in 1841. Previously the anamolous behavior of the discharge of a jar when used to magnetize steel needles had been noticed, but was attributed, as I believe, to some peculiarity of the steel. Henry was the first to appreciate the true reason, although he could hardly at that time be expected to see the great importance of his discovery.

Helmholtz, in 1847, suggests that the discharge of Leyden jars may be of the nature of a backward and forward movement. There is a curious parallelism in the work of several investigators about this time, and particularly in that of Helmholtz and Thomson. In the Philosophical Magazine for 1855 there is a paper by Prof. W. Thomson (Kelvin) in which the theory of the discharge of a Leyden jar is discussed and the prediction made that under certain specified conditions the discharge must be oscillatory. A number of similar papers, going back to 1848, treat of similar subjects. Henry's results do not appear to have become generally known, and we find the verification of Thomson's prediction in 1857 by Feddersen. A number of other physicists have investigated the subject, the work of Schiller being of particular value. The recent applications will be referred to later.

The mathematical theory of electrostatics and magnetism was greatly extended about this time by Thomson and others, and received its most complete statement at the hands of Maxwell in his papers read before the Royal Society and in his book, published in 1873 but still the standard of reference. Very little has since been discovered which was not foreshadowed by Maxwell's theory or contained in his equations, which have been found general enough to cover almost everything, although experiment has generally been necessary to suggest the consequences of the theory.

The practical applications of electricity have played a most important part in the development of the subject during the last sixty years. Indeed, a great part of the work of these years has had some practical application in view. One of the first of these practical applications was that of telegraphy.

The telegraph, being one of the earliest of the practical developments, naturally had a great effect in stimulating the advance in knowledge of electricity, and hence I give a somewhat fuller sketch of its early history than space will permit for the later applications.

The discovery of Stephen Gray, in 1729, that the electrical influence could be conveyed to a distance by means of an insulated wire is probably the first of direct influence in connection with telegraphy. As a result of this discovery and the investigations which followed it, a considerable number of proposals were made as to the use of the electrical force for the transmission of intelligence. The first of these of which I have found any record was made in 1753 by Charles Morrison, a Scotchman, and then followed other proposals for electrostatic telegraphs by Bozolus in 1767, by Le Sage in 1774, by Lomond in 1787, by Betancourt in the same year, by Reizen in 1794, by Cavalla in 1795, and by Ronalds in 1816.

The discovery of voltaic electricity, and most directly the discovery of Nicholson and Carlisle of electrolysis, gave rise to another group of proposals for the application of this discovery to the production of telegraphy. Among those may be mentioned that of Sömmering in 1809, of Coxe in 1810, and of Sharpe in 1813. In more recent years, of course, the same application appears in the chemical telegraphs, some of which are capable of giving very satisfactory results and great speed.

The discovery which had the greatest influence on the development of telegraphy was that of Oersted, supplemented by the work of Schweigger and Ampere. Ampere proposed a multiple-wire telegraph with galvanoscope indicators in 1820, and a modification was constructed by Ritchie. A single-circuit telegraph of this character was invented by Tribaoillet, but did not come into use. In 1832 Schilling's five-needle telegraph appeared, and he also used a single-needle instrument, but his early death stopped further progress. In 1833 Schilling's telegraph was developed, to some extent, by Gauss and Weber, who used it for experimental purposes. The following quotation, referring to Gauss and Weber's telegraph, from Poggendorf's Annalen, is of considerable historical interest:

"There is, in connection with these arrangements, a great and until now in its way novel project, for which we are indebted to Professor Weber. This gentleman erected, during the past year, a double-wire line over the houses of the town (Göttingen), from the Physical Cabinet to the Observatory, and lately a continuation from the latter building to the Magnetic Observatory. Thus an immense galvanic chain is formed, in which the galvanic current, the two multipliers at the ends being included, has to travel a distance of nearly 9,000 (Prussian) feet. The line wire is mostly of copper, of that known as 'No. 3,' of which 1 meter weighs 8 grams. The wire of the multipliers in the Magnetic Observatory is of copper, 'No. 14,' silvered, and of which 1 meter weighs 2.6 grams. This arrangement promises to offer opportunities for a number of interesting experiments. We regard, not without admiration, how a single pair of plates, brought into contact at the farther end, instantaneously communicate a movement to the magnetic bar, which is deflected at once for over a thousand divisions of the scale."

Further on in the same paper:

"The ease with which the manipulator has the magnetic needle in his command, by means of the communicator, had a year ago suggested experiments of an application to telegraphic signaling, which, with whole words and even short sentences, completely succeeded. There is no doubt that it would be possible to arrange an uninterrupted telegraph communication in the same way between two places at a considerable number of miles distance from each other."

The method of producing the currents in Gauss and Weber's experiments was an application of the important discoveries of Faraday and Henry, above referred to, in the induction of current by currents and by magnets.

On the recommendation of Gauss, this telegraph was taken up by Steinheil, who, following their example, also used induced currents. The important contributions of Steinheil were the discovery of the earth return circuit, the invention of a telegraphic alphabet, and a recording telegraph. Steinheil contributes an account of his telegraph to Sturgeon's Annals of Electricity, in which the relative merits of scopic, recording, and acoustic telegraphs are discussed, and the advantages, which experience has since brought into prominence, of the acoustic form are pointed out.

Schiller's telegraph was exhibited at a meeting of German naturalists held at Bonn in 1835, and was there seen by Professor Muncke, of Heidelberg, who, after his return to Heidelberg, made models of the telegraph and exhibited them in his class room. These models were seen by Cooke in the early part of 1836, and gave him the idea of introducing the electric telegraph in England. Cooke afterwards became associated with Wheatstone, and a large number of ingenious arrangements for telegraphing was the result. Many of the later developments by Wheatstone are still in use and are hard to beat.

Steinheil appears to have been anticipated in the idea of making the telegraph self-recording by Morse, who, according to evidence brought forward by himself, thought out some arrangements as early as 1832. Exactly what Morse's first ideas were seems somewhat doubtful, and he did nothing till 1835, when he made a rough model of an electro-magnetic recording telegraph. Morse's mechanical arrangements were of little merit, and his alphabet and method of interpretation by a dictionary were clumsy and inconvenient. The chief point of interest in connection with the early history of the Morse telegraph was the proposal to make use of Sturgeon's discovery of electro-magnetism of soft iron. Morse, however, seems to have known practically nothing of the subject except that iron could be magnetized by a current, and in consulting his colleague, Dr. Gale, he was unwittingly led to use the discoveries of Henry, who had previously practically solved the whole problem. Much of the subsequent improvement in the mechanical arrangements were due to Vail, who became associated with Morse, and the Morse code as we now know it was almost, if not entirely, worked out by Vail. Considerable dispute and some litigation arose over Morse's claims, but that is outside our present subject. There is no doubt that the electric telegraph was a slow growth, inventors, with a view to pecuniary and other advantage, being ever ready to lay hold of each scientific discovery and try to turn it to account. The question who first conceived the idea can never be satisfactorily answered.

After 1840 there is little to record of a purely electrical character bearing only on telegraphy, but there have been many very ingenious mechanical contrivances introduced for recording signals, for reproducing pictures and handwriting, and for printing, for duplexing, quadruplexing, and multiplexing telegraph lines, for increasing the rate of signaling, and in many ways increasing the expedition with which messages can be sent. Of course the success of many of these contrivances, and even their invention, depended upon an increased knowledge of the laws of electricity and magnetism. For example, effective duplexing, quadruplexing, etc., depends on a proper understanding of the electrostatic capacity of the line, and this was not understood properly until the mathematical investigations of Thomson and others cleared the matter. For the impetus toward discovery in this direction again we are largely indebted to telegraphy, for much of that class of work was suggested by the difficulties encountered in signaling through long submarine cables.

The invention of the telephone is fast becoming ancient history, and yet it will always mark one of the greatest of the useful applications of electricity. It does not call for more than a passing remark here, because electro-magnetically it is all in Faraday's and Henry's papers.

The radiophone should be mentioned because it marks the application of the discovery, by May and Smith, of the effect of light on the resistance of selenium. This effect has since been found in the case of a large number of other substances, but it is still an interesting field for research. A number of experiments on this subject have been associated with attempts to make things visible at a distance. No doubt it will ultimately be possible not only to talk to a distant party, but also to see the party talked to, and thus, as it were, look the party with whom you are conversing in the eye.

The subject of telegraphy is closely associated with the present excellent system of electrical measurements and with the invention of many of our most delicate measuring instruments. As the applications of electricity increased there gradually grew up a new branch of engineering, a branch, however, in which the foot rule, pound weight, chronometer, and thermometer were not sufficient. Other standards of measurement were required, in order that quantities could be gauged and consistent work done. The way to connect the measurements of the new quantities with the units already in use in dynamics had been pointed out by Gauss and others, and at the suggestion of Thomson the British Association appointed a committee in 1861 to determine the best standard of electrical resistance. This led to an unexpected amount of work, not only on a standard of resistance, but also on the general subject of electrical measurement. The committee regretted, at the end of the first year, that it could not give a final report, but hoped that the inherent difficulty and importance of the subject would sufficiently account for the delay. It can hardly be said that the final report has yet been forthcoming, as a committee with some of the original members in it still exists and reports regularly every year on valuable work done by it. The committee worked energetically for a number of years, not only on the standard of resistance, but on those of current, electro-motive force and capacity. It incidentally supplied a great deal of quantitative data on a number of subjects, and particularly as to the permanence of alloys, the variation of their resistance with temperature as depending on their composition, and so forth. In looking over the results of the early work of the British Association committee one is apt to indulge in adverse criticism. It is hard for many of the younger workers to appreciate the difficulties which are met in a first attempt. It would be equally just to congratulate ourselves that we have better marksmen to-day than there were fifty years ago, without making allowance for the modern rifle.

The first absolute determination of resistance was probably that made by Kirchhoff about fifty years ago. Weber published his method in 1852, and then came the British Association determination by Maxwell, Stewart, and Jenkin in 1863. Neither of these was very exact, but they paved the way for the splendid exhibitions of experimental skill which followed. Among those to whom we are most indebted for this later work may be mentioned Kohlrausch, Rayleigh, Glazebrook, Rowland, Wiedemann, Mascart, etc. The greatest step in advance in recent years has been the invention of the revolving-disk method by Lorenz, of Copenhagen, and its subsequent improvement and application by himself and by J. V. Jones. The determinations made by the latter by this method are probably almost absolutely correct.

A subject which has attracted much attention comes in incidentally here, namely, the electro-magnetic theory of light propagation suggested by Maxwell. According to this theory the ratio of the electro-magnetic unit of quantity of electricity to the electro-static unit ought to be the same as the velocity of light. In 1868 a determination of this ratio was made by McKichan under Lord Kelvin's direction, and gave close agreement with the theory. Since that time determinations have been made by various methods by Maxwell, Shida, Ayrtin and Perry, J. J. Thomson, Rosa, Lodge, Glazebrook, and others, with the result that the ratio of the two units does not differ from the velocity of light by more than the probable error of observation. The work here referred to may not appear to be very directly associated with the determination of standards of measurements. It is, however, one of the investigations which has been made possible by the work of the British Association committee in the production of instruments of precision. Prominent among these instruments stands the Kelvin electrometers, and particularly the absolute electrometer which was described in the report of the British Association committee for 1867.

Another subject of great interest in itself and in connection with Maxwell's theory is that of the specific inductive capacity of dielectrics. Experiments on this subject were made by Faraday, but comparatively little was done before 1870, in which year an excellent paper was communicated to the Royal Society by Gibson and Barclay on the specific inductive capacity of paraffin. Since that time much good work has been done by Boltzman, Hopkinson, Quincke, Silow, Klemencic, Negreáno, and others. The theoretical importance of these experiments is due to the fact that, according to Maxwell's theory, the specific inductive capacity of nonmagnetic dielectrics should be proportional to the squares of their indices of refraction. A wonderful verification of Maxwell's theory was carried out only some ten years ago by Hertz, who showed not only that electrical waves exist, but also how to measure their wave length and period. We have in these experiments splendid illustrations of the oscillatory discharge referred to above, as discovered by Henry and predicted by Thomson, and as a result several new ways of determining electrical quantities have been developed. It is now possible, for example, to compare the capacity of condensers by means of oscillatory currents of exceedingly short periods, and thus to determine the dielectric constants of many materials to which the older methods were not easily applicable.

It is somewhat difficult to decide where to place a reference to the recent discovery of Röntgen and its development in photography, but probably it comes in well here. Just how to apply Maxwell's equation to the Röntgen rays is not yet quite clear, but there is no doubt as to the great importance of the discovery.

As an outcome of all this activity in the determination of standards and in the absolute measurements of the electrical properties of materials, combined with the great commercial demand produced by the introduction of dynamo machinery, we have now many excellent instruments at our disposal for absolute measurement and suitable either for practical applications or for the most refined laboratory work. For the production of these we are indebted to a host of inventors, prominent among whom may be mentioned Lord Kelvin, Lord Rayleigh, Ayrton and Perry, Mather, Swinburne, Cardew, and Weston.

Magneto-electric and dynamo-electric generators and motors have now become so common that we are apt to forget that their introduction on an extensive scale has only taken a few years. Faraday's disk dynamo was, as has already been stated, produced in 1831, and a machine for generating electricity was made by Pixii in the following year. Pixii's machine consisted of a horseshoe permanent magnet which was rotated in such a way that its poles passed alternately in front of the poles of a similar electro-magnet. An alternating current was thus induced in the circuit which included the coils of the electro-magnet.

This machine was improved by Clarke, who rotated the coils and put a commutator on the axis. Other machines were made or suggested by various physicists, and an important observation, which has since been frequently overlooked, was made at this time by Jacobi, who pointed out the importance of making the cores of the coils short. Sturgeon, in 1835, made a dynamo with a shuttle-shaped armature; a similar form has long been identified with the name of Siemens. Woolrich made a multipolar-magneto machine in 1841 for electroplating, and Wheatstone about this time produced his small multipolar magneto, long used for telegraph purposes. In 1845 Wheatstone and Cooke patented the use of electro-magnets in place of the permanent magnets, and Brett suggested, in 1848, that the current from the machine might be made to pass round a coil surrounding the magnet and thus increase its strength. A similar suggestion was independently made in 1851 by Sinsteden. In 1849 Pulvermacher proposed the use of thin laminæ of iron for the cores of the magnet, a proposition which has since, but probably for a different reason, been almost universally adopted. Sinsteden used iron wire cores and made a number of experiments on the effect of varying the pole face. About this time another class of machines were proposed by Ritchie, Page, and Dujardin. In these machines both the magnets and the coils were to be stationary, but the magnetism was to be varied by revolving soft iron pieces in front of the poles. Modern representatives of these machines are to be found in the dynamos of Kingdon, Stanley, and others. All the machines up to this time had been of very small dimensions. In 1849 Nollet began the construction of an alternating machine on a larger scale, but died before it was completed. Machines of Nollet's type were afterwards made by Holmes and by the Compagnie l'Alliance, of Paris, the latter being called the Alliance machine. These machines were used for light-house purposes. Holmes's earlier machines were continuous current, but later he left out the commutator, and still later again introduced it on part of the coils for the purpose of obtaining current to excite his field magnets. This latter plan was introduced after the self-exciting principle had been introduced by Siemens and Wheatstone. A remarkable machine, historically, was patented in 1848 by Hjorth. In this machine a combination of the permanent and electro magnet was used, the first to give mechanism enough to produce a current with which to excite the other. A similar idea was developed fifteen years later by Wilde, with the difference that the permanent-magnet part was a separate machine. The idea of using part of the current from the armature to excite, or partially excite, the field magnets was at this time in the minds of a number of workers, and some remarkable machines were patented by the brothers Varley, one of which, containing both a shunt and a series winding, has been held by some to anticipate the compound winding now in use. In 1867 it seems to have occurred independently to Wheatstone and E. Werner Siemens that the permanent-magnet part of the Hjorth and Wilde machines might be dispensed with, the residual magnetism being used to start the action. Siemens gave the name dynamo-electric machine to this type, and it has stuck. In order to diminish the fluctuations in the strength of the current during one revolution of the armature Pacinotti devised his multigrooved armature in 1864. This machine did not receive the notice it deserved for a number of years, and in the meantime Gramme produced his smooth-ring armature, in 1870. Gramme's machine was soon recognized as being of great merit, and its gradual introduction gave rise to increased activity. In 1873 the Hefner-Alteneck improvements on the Siemens armature were introduced and in the remaining seventies quite a number of forms of dynamo were invented, the Lontin type, introduced in 1875 with improvement in subsequent years, being one of the best. The early eighties saw tremendous activity; the patent offices in Europe and America were flooded with inventions of various types of dynamos and motors, of lamps for electric lighting, etc. It is curious how few of those machines have stood the test of time and how well the old types of Pacinotti, Gramme, Siemens-Alteneck, and Lontin in some one of their modifications hold the field. Great progress has been made in the last fifteen years. Machines have assumed enormous proportions and the number of branches of industry to which they have been applied is now very large. Much has been learned during this time, particularly with regard to alternating currents and their application to the transmission of power, the introduction of Multiphase systems being of considerable importance in this connection. In the direction of high potential and great frequency the work of E. Thomson and Tesla is of great interest.

Of the application of electricity to the production of light and heat little need be said in this connection. The difficulties to be overcome were largely mechanical, and with the progress made we are all familiar.

As regards primary batteries there has been, of course, as we all know, considerable progress since the time of Volta. The number of forms brought into use has been enormous and they have been important in increasing our knowledge of the relative electro-motive force of various combinations and in their bearing on chemical knowledge. It can hardly be said that an ideal primary battery has yet been obtained, when we look at the subject from a commercial point of view. Although the subject is not very much to the front at present, however, it is destined to come again, and will, I have no doubt, be in a comparatively short time one of our leading industries.

The work of Planté and of Faure and others on secondary batteries has been of great value commercially. They gave rise to several chemical problems, but the main difficulty here also has been of a mechanical kind, and they have not added much to the knowledge of electrical laws.

The transformation of alternating currents from high to low potential and vice versa, by means of what are commonly called transformers, has shown another remarkable development of Faraday's discovery of induced currents. The application of transformers has made it possible to distribute electrical energy over large areas in a moderately economical manner, and incidentally has led to considerable increase in the knowledge of the magnetic properties of iron.

One of the most important of the applications of electricity is that of electro-chemistry. The chemical action of the electric spark was noticed by Van Groest and Dieman in 1739 in the decomposition of water. Beccari, about the middle of the eighteenth century, obtained metals from oxides through which the spark had passed, and in 1778 Priestly noted the production of an acid gas when the electric spark was passed through air. Similar experiments were made by Cavendish and Van Marum on decomposed ammonia. It is not, however, until after the discovery of the voltaic cell that the subject of electrolysis really begins. I have already referred to the discovery of Nicholson and Carlisle in 1800, and the subsequent work of Davy and of Faraday. The peculiar phenomenon of the appearance of separated elements only at the end plates in the electrolytic cell led to considerable speculation, and was explained by Grothuss on the supposition that the molecules separated into two parts, one positively and the other negatively electrified, and that these parts formed a chain between the plates along which chemical action traveled by a continual interchange of mates, the end parts going to the plates. This theory was held for many years, and is still to be found in some text-books. Faraday's work is by far the most valuable of the early contributions to the subject. He gave the following laws:

The amount of chemical decomposition in electrolysis is proportional to the current and the time of its action.

The mass of an ion liberated by a definite quantity of electricity is directly proportional to its chemical equivalent weight.

The quantity of electricity which is required to decompose a certain amount of an electrolyte is equal to the quantity which would be produced by recombining the separated ions in a battery.

These laws are all of the greatest importance, and the last one clearly points out the reversibility of the electrical process. By forcing a current through an electrolyte it is decomposed and the mutual potential energy of the components consequently increased. By allowing the components to recombine in a battery the mutual potential energy is reduced and a current of electricity is the result. An excellent illustration of this action is exhibited by the secondary battery.

In 1857 Clausius gave a theory of electrolysis and at the same time reviewed the weaknesses of the hypotheses of Grothuss and others. Clausius assumes that the molecules of the liquid are in continual motion; that impacts frequently occur which produce temporary dissociation, leaving atomic groups charged with opposite electricities, and that during these separations any directive agency, such as an electromotive force, is able to cause a motion of these atoms in opposite directions. This is probably the first indication of the idea of the purely directive character of the applied electro-motive force taking advantage of dissociation to produce chemical separation.

The energy side of the problem now began to attract attention, and the development of what may be called the thermodynamics of electrochemistry began. Among the most prominent workers in this field have been Joule, Helmholtz, Gibbs, Kelvin, Boscha, and Favre.

In 1853 Hittorf made quantitative determination of the change of concentration near the electrodes when a current is passed through a solution. This work is of historical interest, because it formed practically the starting point for what may be called the modern view of electrolysis. Hittorf's experiments extended over several years and served practically to establish the theory of the migration of the ions in the solution. Hittorf communicated the following laws:

The change in concentration due to current is determined by the motion which the ions have in the unchanged solution.

The unlike ions must have different velocities to produce such change of concentration.

The numbers which express ionic velocities mean the relative distance through which the ions move between the salt molecules, or express their relative velocities in reference to the solution, the change in concentration being a function of the relative ionic velocities.

Hittorf's analyses enabled him to give numerical values to these relative velocities. The experiments of Nernst, Loeb, and others have extended Hittorf's results, and have shown that in dilute solutions the relative velocities of the ions are independent of the difference of potential between the electrodes, and are only slightly, if at all, influenced by temperature. Hittorf pointed out that a knowledge of the conductivity of electrolytes should give valuable information in reference to the nature of electrolytic action. A great deal of work has been done in this direction by Horsford, Wiedemann, Beetz, the Kohlrauschs, and others. The most notable, perhaps, was the work of F. Kohlrausch, who devised a method of measurement using alternating current, by which results of high accuracy were obtained. Kohlrausch's results give the sum of the ionic velocities, and thus, combined with the results of Hittorf on change of concentration, which gave the ratios, the absolute velocity can be obtained. It appears from these results that the velocity of the ion in very dilute solutions depends only on its own nature and not upon the nature of the other ions with which it may be associated. For example, the velocity of the chlorine ion is the same when determined from solutions of KCl, NaCl, or HCl. The important general law has also been found that the conductivities of neutral salts are additively made up of two values, one dependent on the positive, the other upon the negative ion. If, then, the velocities of the ions themselves be known, the conductivity of a salt may be calculated. The results of Kohlrausch received strong confirmation from some very ingenious experiments by Lodge and Whetham, in which the migration of the ions was made to produce a change of color in the solution, and could thus be directly observed.

In 1887 the theory was advanced by Arrhenius and Ostwald that dissociation is directly effected by solution or fusion and that in very dilute solutions the dissociation is practically complete. Arrhenius holds that the ions carry charges of electricity, positive or negative, dependent upon their nature, but of equal quantity in every ion. The remaining part of the theory is similar to that of Clausius and others. According to this theory the ratio of electric conductivities for different densities of solution gives a measure of the relative dissociation or ionization. If the act of solution effects the dissociation necessary to admit of electrolysis, chemically pure substances ought not to be decomposed by the electric current, and this is found to be the case. It is curious that two substances like hydrochloric acid and water, which separately are insulators, should, when mixed, conduct readily, and that practically only one of them should be decomposed. This, however, is only one of the many problems still to be solved. Another question is how do the ions obtain their electric charge? Still another, what is the nature of the force which causes ionization? There are many more.

When we turn to the commercial application of electro-chemistry we are met with astonishing evidence of activity. Only twenty years ago there was comparatively little evidence of the importance of this branch of applied electricity. At the electrical exhibition in London in 1881 electro-chemistry was apparently of comparatively little prominence. A factory which could annually produce a few hundreds of tons of copper electrolytically was considered a wonder. The production of thousands of tons a month is beginning to be looked upon as commonplace. There is scarcely a metal which can not be deposited electrolytically with comparative ease, and the prices of some of the rarer metals is going down rapidly. Zinc used to be considered a difficult metal to deposit successfully. It is now produced in some of the Australian mines in almost a pure state from refractory ores at the rate of thousands of tons per annum. Similarly the old method of galvanizing is rapidly disappearing and electro-deposition is taking its place, and this metal is now so deposited on the hulls of ships, on anchors, and other smaller articles, cheaply and perfectly. A new industry has practically sprung up, and there is every indication that the technical chemist of the near future will have to take an inferior place unless he be also well versed in electricity and electrical appliances. This branch of applied science is revolutionizing many things. It has within a few years produced an enormous improvement in our magazine illustrations, and has at the same time reduced the cost of this kind of literature and of atlases and charts enormously. Electro-chemistry is now used on a large scale for the production of chlorate of potash, bleaching materials, alkalies, coloring matters, antiseptics (like iodoform), anæsthetics (like chloroform), etc. In fact, it is getting to be difficult even to enumerate the manufactures in which it is used. It has revolutionized the extraction of gold, and plants of enormous capacity are now in use in some of the gold fields, the poorest ores and tailings being made to yield up almost the last trace of the precious metal. The production of ozone by the ton, the purification of sewage, and the sterilization of water are all accomplished facts.

Some progress has even been made in the introduction of chemicals through animal tissue by electrolysis or cataphoresis, and Röntgen has shown us how to see through the body.

Then, again, we have got the electric furnace, and with it the power to fuse almost the most refractory substances. In this way aluminum is now produced at a few cents a pound, whereas most of us remember when its price had to be reckoned in hundreds of dollars. In a similar way phosphorus is now produced on a large scale, as are also various carbides, carborundum, acetylene, etc.

It is impossible to look back over the history of electricity and its applications and notice the apparent geometric ratio in which advances are being made, and not to speculate on what a giant this science is going to become in another quarter of a century. Undoubtedly no one can study this one branch of science without being persuaded of the great value of scientific work for the advancement of human enterprise.

TELEGRAPHY ACROSS SPACE.[1]

By SILVANUS P. THOMPSON, F. R. S.

There is no such thing as wireless telegraphy. True, one can send signals for a distance of a yard or two without any wires, but in all the recent successful attempts to telegraph across space, whether by electric waves or by other means, wires are used. They do not indeed run from the sending station to the receiving station, but are used as base lines. For example, in the case of the longest distance yet reached in telegraphing by electric waves—13 miles over open country—the maximum distance obtained in the recent experiments of Professor Slaby, the length of the wires used as base lines at each end was nearly 1,000 feet. As will be seen, in every case, wires or their equivalent are used to serve either as base lines or as base areas in the transmission.

Setting aside the mediæval myth of a sympathetic magnetic telegraph with two mere compass needles to point to letters ranged around a dial, there are three generic methods by which it has been found possible to signal across space without any directly communicating wire or cable. These may be conveniently classified as follows:

I. Conduction methods.
II. Induction methods.
III. Wave methods.

I.—CONDUCTION METHODS.

These methods depend upon the use of water or earth as a means of conducting a fraction of the electric current from the base line at the sending end to the base line at the receiving end.

From the earliest days of telegraphy it has been a familiar fact that either earth or water might serve as a return circuit for an electric current; and, under certain circumstances, that signals could be sent even with an absolute gap in the metallic line, if there were provided, by means of earth or water, a sufficiently good path to enable current in adequate amount to be received beyond the gap in the line. This method has sometimes been called the leakage method, since it depends upon the circumstance that electric currents flowing in a conducting

[1] From Journal of the Society of Arts, Vol. XLVI, London, 1898, pp. 453–460.

medium, such as water or moist earth, do not flow exclusively or even mainly along the path of least resistance, but spread out, some flowing along paths of greater resistance. If current enters a conducting stratum at any point by a single electrode, A, and leaves it at some other point by another suitable electrode, B, some of the current will certainly flow straight from A to B; yet the greater part will not so flow, but will stream around from A to B in long curving paths. If then, two other electrodes, C and D, are inserted in one of these stream paths at a distance from A to B, some of the current, perhaps only a small percentage of it, may be picked up by a metallic line joining C to D. Hence it is possible, using A B as a sending base line, to signal to C D as a receiving base line at a distant place. The only limits to this method of telegraphy across space are (1) the strength of the original currents used in the sending base line A B; (2) the sensitiveness of the apparatus used in the receiving base line C D; (3) the ratio between the space distance from A B to C D and the lengths of the two base lines. This system of telegraphing across space has been proposed at various times. It has been used by Mr. Preece in several of those many experiments which he has made from time to time, and which will entitle him to be regarded as one of the foremost pioneers in this entire branch of telegraphic enterprise.

Morse himself, as recorded in Vail's early work on telegraphy, worked at this subject and made experiments in 1842 on the Susquehanna River, about a mile wide. He engaged Professor Gale to investigate the best conditions, and came to the conclusion that the base lines should be three times as long as the distance to be crossed. Mr. Dering, an English telegraph engineer, and Mr. Lindsay, of Dundee, have also worked in this direction.

After the introduction, in 1877–78, of the Bell telephone, it was found that the extraordinary sensitiveness of that instrument furnished a new means of picking up currents that would otherwise be too feeble to produce intelligible signals. The importance of this circumstance in extending the possibilities of distance telegraphy was not lost upon Mr. Preece. In 1882 he conducted a series of researches upon the establishment of telegraphic communication between the Isle of Wight and the Hampshire coast without any connecting cable across the Solent. An account of these experiments will be found in the report of the British Association for that year. Large metal plates, to serve as electrodes, were immersed in the sea at the ends of the two base lines. On the Hampshire coast the base line extended from Portsmouth through Southampton to Hurst Castle, a length of 20 miles. On the island the base line extended from Ryde through Newport to Sconce Point, and was about 16 miles long. From Portsmouth to Ryde the breadth of the sea is 6 miles, while Hurst Castle is only about a mile from Sconce Point. Hence, in this case, the length of the base lines considerably exceeded the average distance to be crossed.

With this arrangement signals were passed in dot and dash which could be read on the Morse system with ease, but telephonic speech was not feasible. After many other experiments to be mentioned under the next heading, Mr. Preece established communication, in the winter of 1893–94, across the Kilbrannen Sound between the Isle of Arran and Kintyre, a distance of over 4 miles. He also maintained telephonic speech across Loch Ness, a distance of 1¼ miles.

In the experiments from Arran to Kintyre, parallel wires about 3 miles long were used as base lines along the coast, while in some of the experiments two other base lines were used, being insulated wires laid along each coast at a height about 500 feet above the sea level. A detailed account of these experiments will be found in the report of the British Association for 1894, and is also given in The Electrician, Vol. XXXIII, August 17, 1894.

A year earlier Mr. Preece had made some striking experiments in the Bristol Channel between Lavernock Point on the South Wales coast and the islands of the Flat Holm and the Steep Holm, the distances of which are respectively 3.1 and 5.35 miles. His base line on the shore at Lavernock Point was a pair of copper wires, weighing 400 pounds per mile, suspended on poles for a length of 1,267 yards, their circuit being completed through earth. An alternating current was sent into this base line by an alternator worked by a 2-horse power steam engine, the voltage being 150 volts, the frequency 192 periods per second, and the current (maximum) 15 amperes. These alternations were broken up into dots and dashes by use of a Morse key. The signals were read on a pair of receiving telephones inserted in the distant base line, which, in each case, ran across the island and dipped into the sea. The length of these is not stated. Mr. Preece received messages easily over the 3 miles separating the mainland from the Flat Holm, but with Steep Holm 5. 35 miles away, though the signals were feebly perceptible, telegraphic conversation was impracticable, as the sound could not be differentiated into dots and dashes. Mr. Preece came to the conclusion that with two base lines, each 10 miles long, he could with ease signal across a distance of 10 miles.

Professor Trowbridge, of Harvard, has also investigated the possibility of transmitting signals through the earth by conduction, using a rapidly interrupted primary current and a telephonic receiving apparatus.

Many experiments have been made under accidental circumstances, all tending to prove the possibility of this mode of transmitting signals through the earth itself. The instruments in Greenwich Observatory are affected by the stray currents that escape into the earth from the badly insulated return circuit of the City and South London Electric Railway, 4½ miles away. Another example is afforded by an accident which occurred some ten years since at the Ferranti electric lighting station at Deptford, when one night one of the dynamos by some derangement became connected to earth. The whole of the railway telegraphs in the signal boxes of the railways in South London were temporarily put out of order and rendered inoperative, while the currents flowing in the earth were perceived in the telegraph instruments so far northward as Leicester and so far south as in Paris. If this could occur as a mere accident, it is obvious that, with properly thought out arrangements, signals could easily be sent from one part of the globe to another by conduction through earth or water.

Most striking of all the cases of distance signaling by conductive methods is that presented by the transmission of signals over nearly 3 miles, which was carried out in 1894 by Dr. W. Rathenau, Mr. E. Rathenau, and Professor Rubens. They selected as a suitable place for operations the open water of the Wannsee, which opens into the Havel, near Potsdam. Here at the south end, near the Friedrich-Wilhelms-brücke, they immersed two metal electrodes, each having about 15 square meters of surface, at the two ends of a base line about 550 feet long. With 75 accumulators and a rotating interrupter, giving about 150 currents per second, and a Morse key they injected signals into the base line. At a distance of 4½ kilometers, or nearly 3 miles across the water, near the shore at Neu Cladow, they set up the secondary base line, having electrodes of about 4 square meters each. These were hung in the water from two boats between which the connecting line, about 330 feet long, was stretched. In this line was inserted a telephone receiver of usual pattern. The current used was about 3 amperes, and there was not the slightest difficulty in hearing the dot-and-dash messages. Several situations for the receiving base line were tried; it appeared that the interposition of a large sand bank between the two stations made very little difference.

II.—INDUCTION METHODS.

Induction methods are of two varieties. An electric charge upon a conductor may induce another electric charge at a distance by influence, or electrostatic induction. An electric current in a wire, during such time as it is increasing or diminishing, may induce another electric current in another wire in its neighborhood by electro-magnetic induction.

So far as I am aware, the only case in which electrostatic induction has been used in electric signaling is that of telegraphing (or telephoning) to trains in motion, as suggested about thirteen years ago by Mr. Wiley Smith, of Kansas City. If a wire suspended over a train is electrified, either positively or negatively, charges are induced upon the metallic roofs of the cars, and if these are suitably connected to instruments on board the train, signals may be exchanged between train and wire without any metallic connection between the two. This suggestion was further developed about the year 1886 by Mr. Phelps and by Messrs. Gilliland and Edison. Descriptions of their methods will be found in the American electrical journals of that date. The system was successful both for telegraphing and telephoning, and was indeed adopted for a time by the Lehigh Valley Railroad Company. But it has been abandoned for a very simple reason. One of the consolations of railway traveling is that one is free from being disturbed by telegraph or telephone. No one on board an express wants to telegraph or to be telegraphed to.

Electro-magnetic induction has played so an important a part in distance telegraphy that it must receive a more extended notice. Very early after the introduction of the commercial telephone, troubles arose from the exceeding sensitiveness of the instrument. Conversations in one line were overheard in another; while the ear was disturbed by an incessant buzz, or rattle, from the interference of stray currents from neighboring telegraph lines. All these were at first attributed to induction; that is to say, to the electro-magnetic influence of the currents in one line upon the neighboring line. No doubt, in some cases, this is a cause; but unquestionably, in many of the cases, the disturbance was due not to induction at all, but either to leakage of currents across the surfaces of the insulating supports, over films of dirt or moisture, or else to leakage of currents from one line into the other through the earth plates or earth connections. Unless circuits with metallic returns are used, it is certain that the earth return will afford a means for stray currents to find their way into the telephone lines. Mr. Preece has narrated many cases in which telegraph or telephone messages that are being transmitted along some line have been heard, or rather overheard, in telephonic instruments in some totally disconnected and distant line. Many of these are due doubtless to stray currents through earth; but some are unquestionably due to true induction. A line or circuit absolutely insulated from any earth contact or earth return may yet act inductively. During the brief instant while the current in it is growing, that current is setting up a magnetic field in the surrounding region, extending indefinitely, but feebly, into space. As the current dies away again, this magnetic field also dies away. If in its growth or decrease, this magnetic field encounters other wires, it sets up electro-motive forces in them, and thus originates disturbances. For the propagation of this effect from wire to wire no contact is needed. It is an effect that is dependent upon the properties of the intervening medium, and is proportional to its magnetic permeability. The ether of space itself, air, water, soil, and rock, all are of about equal permeability. Hence this kind of induction may be propagated from circuit to circuit, whatever natural material intervenes. Mr. Preece has made repeated researches with the view of utilizing this effect for the purpose of distance telegraphy. He has erected parallel base lines, sometimes in South Wales, sometimes near the mouth of the Dee, sometimes in Scotland. He has laid out, flat on the ground, great squares of insulated wire, to test the inductive transmission from one area to another. On Newcastle town moor, and on the sands at

Penarth, he has thus operated. It is not always easy in his experiments, particularly in those where earth connections were used, to be certain how much of the effect was due to true induction, and how much to earth induction. But in some of the cases there can be no doubt whatever. An excellent résumé of this work was given by him at the Chicago congress in 1893. In this he describes how, in one series of experiments, he laid out on a level plain two one-fourth-mile squares of copper wire insulated with gutta-percha, the distance between the two nearest sides of the two squares being also a quarter of a mile. In this case, using rapidly interrupted or vibratory currents, and a Morse key to break them up into Morse signals, and applying in the other circuit a receiving telephone, conversation in the Morse code could be held readily between the two operators. This arrangement precluded all idea of earth induction. In effect, Mr. Preece was working with a strange species of transformer, of which his two squares constituted respectively the "primary" and the "secondary," the "core" of the transformer being in this case partly of earth and partly of air. Mr. A. W. Heaviside has described an analogous case in which, wishing to establish telephonic communication to the bottom of a colliery in the north of England, he arranged a circuit in a triangular form along galleries about 2¼ miles in total length, at a depth of 60 fathoms. On the surface of the colliery another circuit was laid out in triangular lines of equal size, over and parallel to the underground line. Here, again, telephonic speech was perfectly clear by induction from line to line, or rather, in this case, from area to area. Each area inclosed something like 700,000 square yards, an ample base area when the distance to be penetrated was but 120 yards.

Earlier than the date of either of these experiments, the late Mr. Willoughby Smith had shown how, using two coiled circuits of wire at a distance of some yards apart, telephonic messages could be sent across air, or even through walls and floors.

The greatest distance to which Mr. Preece's experiments upon telegraph lines have been carried is 40 miles, namely, between the telegraphic lines that run across the Scottish border by the east and west coasts respectively. Sounds produced in the Newcastle and Jedburg line were distinctly heard on the parallel line at Gretna, though there was no line connecting the two places. Here, however, since both lines used earth returns, it is probable that most of the effect was due to conduction, not to true induction.

Instruments which operate by means of alternating currents of high frequency, like Mr. Langdon-Davies's phonophore, are peculiarly liable to set up disturbance in other circuits. A single phonophore circuit can be heard in lines a hundred miles away. When this first came to my notice it impressed me greatly; and, coupled in my mind with the Ferranti incident, mentioned above, caused me to offer to one of my financial friends in the city, some eight years ago, to undertake seriously to establish telegraphic communication with the Cape, provided £10,000 were forthcoming to establish the necessary basal circuits in the two countries, and the instruments for creating the currents. My offer was deemed too visionary for acceptance. The thing, however, is quite feasible. The one thing necessary is the adequate base lines or areas. All the rest is detail.

One must not close this section without reverting to a most pregnant point of advance made about 1888 or 1889 by Dr. Oliver Lodge. When experimenting upon the oscillatory discharge he conceived the happy idea of turning two circuits into resonance; or, as he termed it, "syntony" with one another, in such a way that when an oscillating electric spark occurred in one of the circuits the inductive effect on the other immediately set up in it electric oscillations which manifested themselves by an overflow spark. I call this experiment pregnant, because it affords a hint of another possibility, namely, that of signaling inductively from one area to another, and using around those areas not merely circuits of wires, but syntonic circuits, which, therefore, are necessarily much more sensitive in their response one to the other. Some of Tesla's high-frequency experiments also have an obvious bearing on this point.

III.—ELECTRIC WAVE METHODS.

After Clerk-Maxwell had predicted the existence of electro-magnetic waves, and had shown that their speed of propagation is identical with that of light, it required in reality very little to demonstrate by experiment the existence of such waves. But that very little was not actually achieved until the year 1888, when the lamented Prof. Heinrich Hertz showed simple methods of producing, detecting, and measuring these waves. It had been known for many years from the predictions of Kelvin and von Helmholtz, and confirmed by the experiments of Feddersen, that in many cases an electric discharge is of an oscillatory character. In the years 1887–88 Lodge, Fitzgerald, and others were investigating the nature of these oscillations and the manner in which they are guided by conducting wires, when Hertz conceived the idea of investigating the disturbances which such oscillatory discharges set up in the surrounding space. He showed that, given a simple apparatus, which he called an "oscillator," consisting of two metal plates or conductors, connected by a conductor interrupted at one intermediate point by a "spark-gap," the oscillator on the appearance of each spark emitted a train of electric waves into the surrounding space. He further showed that if a mere circuit or ring of wire of suitable size, the continuity of which is interrupted at one point by a minute gap, is placed in the path of these traveling waves in a suitable position, the waves as they reach it set up electric surgings in this wire; and, if sufficiently energetic, cause it to show a small spark in the gap. This simple detecting device he termed a "resonator." Armed with these apparently primitive pieces of apparatus, he then devoted himself to the task of exploring the propagation of the waves. He found that, like waves of light, they could be deflected by metallic surfaces, could be refracted by prisms, concentrated by lenses, and even could be polarized. He measured their wave length and velocity of propagation. He found that they could pass readily through walls of wood, stone, or brick, which are opaque to ordinary light waves. Metals and other conductors of electricity, on the contrary, absorbed them, and were consequently opaque.

In these researches of Hertz we meet, for the first time,[1] with the recognition of a true traveling wave. With this immense discovery, there was opened out an entirely new field of possibilities. Hitherto, there had been inductive actions known which might reach out from wire to wire only to fall back again when their excitant cause dies away. But now the electric wave, once started on its path, did not collapse back into the wires when the spark ceased. On the contrary, it went traveling on. And just as the javelin, which can travel on after the impulse has ceased, can act at greater range than the sword, whose thrust is limited by the length of arm and blade, so the true electric wave, by the very fact that it is a true traveling wave, can carry signals to greater distances than the mere inductive influence that simply extends outwards from a wire or from a coil.

The work which Hertz had begun, was, after his death, carried on by a whole army of investigators. Of these, and of their achievements, the best account that has yet appeared is Professor Lodge's little book on The Work of Hertz and his Successors. To that book inquiries must be recommended for details. Suffice it here to say that much has been done in perfecting both the oscillator and the detector. Notable among these matters have been the forms of oscillator designed by Lodge and by Righi; the latter having the spark gap immersed in oil or vaseline between two metal balls. Many forms of detector have been proposed. Very early Lodge produced one under the name of "coherer," consisting of a metallic point very lightly pressed against a metal plate, and connected in circuit with a galvanometer and a local cell. The light contact constitutes an imperfect joint, which is practically nonconductive until caused to cohere and conduct by the impact of an electric wave; or, perhaps more accurately, by the stimulus of the minute surging electric current which results from the impact of an electric wave. Subsequently, taking a hint from M. Branly, Lodge substituted as a detector a new kind of coherer, consisting of a

[1] Many years before, Prof. Joseph Henry had transmitted induced electric sparks from one circuit to another in different floors of a building. Doubtless these were oscillatory; but it is impossible, at this time, to determine whether the arrangements were such as to produce true traveling waves, or whether the action was (like Lodge's later experiment of the two syntonic circuits) merely one of electro-magnetic induction.

small glass tube partly filled with loose metallic filings—iron or nickel by preference—joined in the circuit. Such a coherer acts as a species of relay, by means of which an electric wave, incapable in itself of affecting a galvanometer or other instrument, is enabled to do so indirectly by setting into operation a local current. After the coherer has thus operated, it usually remains in the conductive state until subjected to some mechanical jar or shock. Lodge proposed to apply for this purpose a mechanical taper worked either by clockwork or by a trembling electric mechanism. On several occasions, and notably at Oxford, in 1894, he showed how such coherers could be used in transmitting telegraphic signals to a distance. He showed that they would work through solid walls. Lodge's greatest distance at that time had not exceeded some 100 or 150 yards. Communication was thus made between the University Museum and the adjacent building of the Clarendon Laboratory. For more than eighteen months the Rev. F. Jervis Smith, of Oxford, using a carbon-powder coherer, has maintained communication between his house and the Millard Engineering Laboratory, over a mile away.

Even before this Mr. Nikola Tesla, in a lecture delivered at St. Louis in 1893, had made a further suggestion of great importance. He proposed to transmit electric energy by oscillations to any distance, without communicating wires, by erecting at each end of the stretch a vertical conductor joined at its lower part to the earth, and at its upper to a conducting body of a large surface. This constitutes a vertical base line from which to disseminate the oscillating disturbances.

About two years ago a young Italian, Mr. Marconi, came to this country and succeeded in inducing the British telegraph department to give him facilities for experimenting upon wave-method of transmission. First upon Salisbury Plain, and then across the Bristol Channel, he succeeded in transmitting Morse signals to a greater distance than anyone had previously attained. He sent signals from Lavernock Point to Bream Down—about 9 miles, as the crow flies, over the open channel. To accomplish this he used as base lines two vertical conductors earthed at their lower ends and carrying at the top extended surfaces. He used a Righi transmitter. As receiver he employed the special form of Lodge–Branly coherer, presently to be described. This was connected in the manner Lodge had recommended in a local circuit, and was tapped by a mechanical tapper operated by a vibrating electric mechanism. The local circuit operated a post-office relay connected to a Morse instrument signaling the dots and dashes. The coherer was itself included in the vertical base line. So far all is old. The special coherer used in these experiments by Marconi has very fine metallic powder, chiefly of nickel and silver, in a small glass tube exhausted of air. He also applied shunting resistances to the relay contacts, and interposed a fine iron wire, closely coiled, as an impedance in the local circuit on each side of the coherer.

In 1897, some further experiments were carried on by Professor Slaby, of Charlottenburg, on an even larger scale. He abandoned every one of the novelties introduced by Marconi, and fell back upon the methods previously known. He used a simple Lodge–Branly coherer, employed elevated conductors as base lines, discarded the useless little iron wire impedance coils in the local circuit, and substituted for the post-office polarized relay one made out of a Weston galvanometer. His success shows that all that is essential can be thus attained. He chose as the scene of his operations the Havel, and set up elevated conductors upon the castle of the Pfaueninsel and on the campanile of the church at Sacrow. Thus equipped, he transmitted signals, at first about three-quarters of a mile, then 3 miles across the water. He found trees and masts to interfere with the signals in some degree. He then proceeded, with the aid of the military authorities, to experiment over an open stretch of country—from Rangsdorf to Schönenberg. The elevated conductors were wires raised by means of hydrogen balloons to heights of nearly 1,000 feet. Signals were obtained at a distance of 21 kilometers, or over 13 miles. Neither in Marconi's nor in Slaby's successful operations were syntonic devices employed.

The following table summarizes the results of Marconi's and Slaby's work:

	Distance.	Base line.	Ratio.
Marconi:	*Miles.*	*Feet.*	
Flat Holm (sea)	$3\frac{1}{4}$	150	100
Bream Down (sea)	9	200(?)	250(?)
Spezia (land and sea)	$4\frac{1}{4}$	100	200
Spezia (open sea)	11	100	500
Slaby:			
Sacrow (water and trees)	$\frac{3}{4}$	80	70
Pfaueninsel (water and buildings)	3	200	50
Rangsdorf (land)	$13\frac{1}{2}$	950	70

Commenting on these results, Slaby notes how over an open sea a much greater distance appears to be attained from a base line of given length. Assuming Marconi's best proportion, he calculates the vertical length of a base line needed for communicating across the English Channel at Dover to be 265 feet, while from London to Paris, over land and sea, would require 4,700 feet. He even estimates base lines of 6,600 feet as sufficient, were it not for the curvature of the globe, to serve for communication across the Atlantic.

The most recent improvements made toward perfecting this method of transmission are those of Dr. Oliver Lodge, whose labors, continued during the past few months, are still in progress. He has first reorganized the transmitter apparatus so as to make it a more persistent radiator. It emits longer trains of waves. This has been accomplished by introducing in the path of the oscillations, between the spark-gap and the wings, a few turns of stout wire to act as an impedance coil. By this means the oscillations can be accurately tuned. The receiving apparatus is also tuned; in fact, each apparatus is made to operate both as emitter and as receiver in turn, as required. Lodge has also modified the arrangements of the coherer circuits, to render them more certain of operation, no local current being allowed to pass through the coherer until after it had been affected by the waves. He has, in fact, thoroughly redesigned the sending and receiving instruments upon a rational basis, so that they shall be both less sensitive to stray impulses and more sensitive to properly attuned waves. The results obtained with these have not yet been made public; but employing a siphon recorder as the receiving instrument,remarkable precision of signaling has been attained. Further developments in this direction will doubtless be awaited with much interest. Meantime, in other countries, the United States, Russia, and France, other experimenters are at work. Any account given at the present time will therefore be necessarily incomplete.

In passing finally from a review of that which has already been attained to that which may reasonably be contemplated as within reach of attainment in the near future, I have no wish to assume the rôle of the prophet. Still less would I desire to emulate the example of the imaginative litterateur who, whether his name be Jules Verne or H. G. Wells, stimulates the public curiosity by amazing speculations, and in doing so renders the disservice that the public so stimulated is made less capable than before of distinguishing between that which is and that which is not within the bounds of reasonable possibility.

It has been shown that there are three general methods of transmitting electric signals across space. All of them require base lines or base areas. The first, conduction, requires moist earth or water as a medium, and is for distances of less than 3 miles the most effective of the three. The second, induction, is not dependent upon earth or water, but will equally well cross air or dry rock. The third, electric-wave propagation, requires no medium beyond that of the ether of space, and is, indeed, interfered with by interposing things, such as masts and trees. Given proper base lines or base areas, given adequate methods of throwing electric energy into the transmitting system and sufficiently sensitive instruments to pick up and translate the signals, it is possible, in my opinion, to so develop each of the three methods that by any one of them it will be possible to establish electric communication between England and America across the intervening space. It is certainly possible either by conduction or by induction; whether by waves I am somewhat less certain. Conduction might very seriously interfere with other electric agencies, since the waste currents in the neighborhood of the primary base line would be very great. It is certainly possible either by conduction or induction to establish direct communication across space with either the Cape or India or Australia (under the same assumptions as before) and at a far less cost than that of a connecting submarine cable. I doubt very greatly whether the wave method can be made applicable at all to these so distant parts of the globe. But whether by conduction, by induction, or by waves, I am firmly convinced that the immediate road to commercial success lies in two things. Firstly, we must frankly recognize that there is no such thing as telegraphing without wires; that the base line or the base area surrounded by wires is a fundamental necessity. Secondly, we must look to establishing real syntony between the sending and the receiving parts of the apparatus to render it, as far as possible, sensitive and independent, without which conditions such systems will become too costly and too unmanageable for commercial ends.

(The paper was illustrated by numerous slides illustrating the methods and instruments used by Hertz, Lodge, Righi, Marconi, and Slaby in their investigations, and the newest syntonic apparatus of Lodge. Experiments were also shown illustrating the transmission of electric waves and their reception and detection. A small Lodge apparatus, constructed by Mr. Miller, was also exhibited in operation.)

The chairman said no doubt all present had come with great expectations, anticipating much pleasure in hearing of the latest developments of one of the most interesting and valuable applications of modern science to useful purposes—electric telegraphy. But whatever their expectations, they must have been more than realized by the exceedingly lucid exposition by Professor Thompson of a most intricate and difficult subject; so lucid in fact had it been that probably few realized how intricate it was. He felt with Professor Thompson that perhaps in the immediate future the application of wireless telegraphy to practical purposes was not quite so wide as some might have anticipated and hoped; but at the same time there were purposes to which they might reasonably hope it might be applied, such, for example, as communication between the shore and lightships, and possibly between ship and ship. It was satisfactory to learn that means were being sought for, and had been to some extent found, of differentiating one telegraphic signal sent through space by another tuning. That was to him a practically interesting point, and the explanations which had been given of the methods adopted by Prof. Oliver Lodge for obtaining the transmission of a particular message, and the receipt of that message by a particular person intended to receive it, were especially valuable. Obviously it would be very inconvenient if messages sent through space were indifferently receivable by everyone who chose to play the part of an eaves dropper. That condition of things would somewhat resemble that described in one of Hans Christian Andersen's stories, where the fumes coming from a pipkin revealed to everyone who chose to smell them what each particular person was having for dinner. It was not very desirable that that kind of curiosity should be gratified in connection with telegraphy, and it seemed to him that the uses of telegraphy through space would be very much limited if this sort of thing could not be prevented. Professor Lodge's line of experiment, however, seemed to tend in that direction, and to show the means of confining a message to the person intended to receive it. He was sure Professor Thompson would be pleased to answer any questions on any point that had not been made clear, if there were any such, any questions which could arise having been already answered in anticipation. If no one had any such query to put, he would conclude by proposing a hearty vote of thanks to Professor Thompson for his paper.

The vote of thanks was carried unanimously, and the meeting adjourned.

SIGNALING THROUGH SPACE WITHOUT WIRES.[1]

By W. H. Preece, Esq., C. B., F. R. S., M. Inst. C. E.

Science has conferred one great benefit on mankind. It has supplied us with a new sense. We can now see the invisible, hear the inaudible, and feel the intangible. We know that the universe is filled with a homogeneous continuous elastic medium which transmits heat, light, electricity and other forms of energy from one point of space to another without loss. The discovery of the real existence of this "ether" is one of the great scientific events of the Victorian era. Its character and mechanism are not yet known by us. All attempts to "invent" a perfect ether have proved beyond the mental powers of the highest intellects. We can only say with Lord Salisbury that the ether is the nominative case of the verb "to undulate." We must be content with a knowledge of the fact that it was created in the beginning for the transmission of energy in all its forms, that it transmits these energies in definite waves and with a known velocity, that it is perfect of its kind, but that it still remains as inscrutable as gravity or light itself.

Any disturbance of the ether must originate with some disturbance of matter. An explosion, cyclone, or vibratory motion may occur in the photosphere of the sun. A disturbance or wave is impressed on the ether. It is propagated in straight lines through space. It falls on Jupiter, Venus, the Earth, and every other planet met with in its course, and any machine, human or mechanical, capable of responding to its undulations indicates its presence. Thus the eye supplies the sensation of light, the skin is sensitive to heat, the galvanometer indicates electricity, the magnetometer indicates disturbances in the earth's magnetic field. One of the greatest scientific achievements of our generation is the magnificent generalization of Clerk-Maxwell that all these disturbances are of precisely the same kind, and that they differ only in degree. Light is an electromagnetic phenomenon, and electricity in its progress through space follows the laws of optics. Hertz proved this experimentally, and few of us who heard it will forget the

[1] From proceedings of the Royal Institution of Great Britain, Vol. XV, Part II, No. 91, April, 1898, pp. 467–476. Read at weekly evening meeting, Friday, June 11, 1897.

admirable lecture on "The work of Hertz" given in this hall by Prof. Oliver Lodge three years ago.[1]

By the kindness of Prof. Silvanus Thompson I am able to illustrate wave transmission by a very beautiful apparatus devised by him. At one end we have the *transmitter* or oscillator, which is a heavy suspended mass to which a blow or impulse is given, and which, in consequence, vibrates a given number of times per minute. At the other end is the *receiver* or resonator, timed to vibrate to the same period. Connecting the two together is a row of leaden balls suspended so that each ball gives a portion of its energy at each oscillation to the next in the series. Each ball vibrates at right angles to or athwart the line of propogation of the wave, and as they vibrate in different phases you will see that a wave is transmitted from the transmitter to the receiver. The receiver takes up these vibrations and responds in sympathy with the transmitter. Here we have a visible illustration of that which is absolutely invisible. The wave you see differs from a wave of light or of electricity only in its length or in its frequency. Electric waves vary from units per second in long submarine cables to millions per second when excited by Hertz's method. Light waves vary per second between 400 billions in the red to 800 billions in the violet, and electric waves differ from them in no other respect. They are reflected, refracted and polarized, they are subject to interference, and they move through the ether in straight lines with the same velocity, viz, 186,400 miles per second—a number easily recalled when we remember that it was in the year 1864 that Maxwell made his famous discovery of the identity of light and electric waves.

Electric waves, however, differ from light waves in this, that we have also to regard the direction at right angles to the line of propagation of the wave. The model gives an illustration of that which happens along a *line of electric force;* the other line of motion I speak of is a circle around the point of disturbance, and these lines are called *lines of magnetic force.*[1] The animal eye is tuned to one series of wave; the "electric eye," as Lord Kelvin called Hertz's resonator, to another. If electric waves could be reduced in length to the forty-thousandth of an inch we should see them as colors.

One more definition, and our ground is cleared. When electricity is found stored up in a potential state in the molecules of a dielectric like air, glass, or gutta-percha the molecules are strained, it is called a *charge*, and it establishes in its neighborhood *an electric field.* When it is active, or in its kinetic state in a circuit, it is called a *current.* It is found in both states—kinetic and potential—when a current is maintained in a conductor. The surrounding neighborhood is then found in a state of stress, forming what is called a *magnetic field.*

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[1]This is published in an enlarged and useful form by The Electrician Printing and Publishing Company.—W. H. P.

[1] Vide fig. 4, p. 256.

In the first case the charges can be made to rise and fall, and to surge to and fro with rhythmic regularity, exciting *electric waves* along each line of electric force at very high frequencies, and in the second case the currents can rise or alternate in direction with the same regularity, but with very different frequencies, and originate *electromagnetic waves* whose wave fronts are propagated in the same direction.

The first is the method of Hertz, which has recently been turned to practical account by Mr. Marconi, and the second is the method which I have been applying, and which, for historical reasons, I will describe to you first.

In 1884 messages sent through insulated wires buried in iron pipes in the streets of London were read upon telephone circuits erected on poles above the house tops, 80 feet away. Ordinary telegraph circuits were found in 1885 to produce disturbances 2,000 feet away. Distinct speech by telephone was carried on through one-quarter of a mile, a

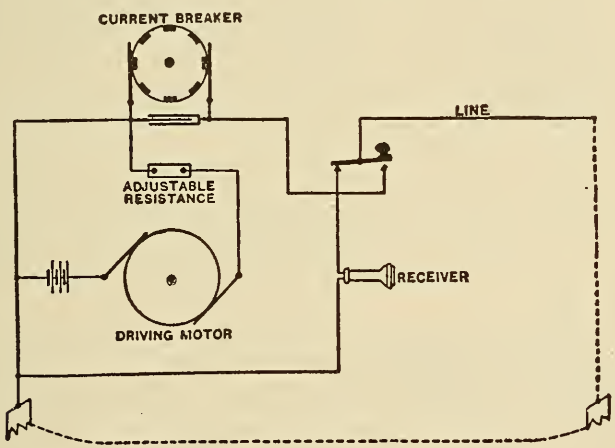

FIG. 1.—Diagram of connections of Mr. Preece's system.

distance that was increased to $1\frac{1}{4}$ miles at a later date. Careful experiments were made in 1886 and 1887 to prove that these effects were due to pure electromagnetic waves, and were entirely free from any earth-conduction. In 1892 distinct messages were sent across a portion of the Bristol Channel, between Penarth and Flat Holm, a distance of 3.3 miles.

Early in 1895 the cable between Oban and the Isle of Mull broke down, and as no ship was available for repairing and restoring communication, communication was established by utilizing parallel wires on each side of the channel and transmitting signals across the space by these electromagnetic waves.

The apparatus (fig. 1) connected to each wire consists of—

(*a*) A rheotome or make and break wheel, causing about 260 undulations per second in the primary wire.

(*b*) An ordinary battery of about 100 Leclanché cells, of the so-called dry and portable form.

(*c*) A Morse telegraph key.

(*d*) A telephone to act as receiver.

(*e*) A switch to start and stop the rheotome.

Good signals depend more on the rapid rise and fall of the primary current than on the amount of energy thrown into vibration. Leclanché cells give as good signals at 3.3 miles distant as 2½ horse-power transformed into alternating currents by an alternator, owing to the smooth sinusoidal curves of the latter. Two hundred and sixty vibrations per second give a pleasant note to the ear, easily read when broken up by the key into dots and dashes.

In my electromagnetic system two parallel circuits are established, one on each side of a channel or bank of a river, each circuit becoming successively the primary and secondary of an induction system, according to the direction in which the signals are being sent. Strong alternating or vibrating currents of electricity are transmitted in the first circuit so as to form signals, letters, and words in Morse character. The effects of the rise and fall of these currents are transmitted as electromagnetic waves through the intervening space, and if the secondary circuit is so situated as to be washed by these ethereal waves, their energy is transformed into secondary currents in the second circuit, which can be made to affect a telephone and thus to reproduce the signals. Of course their intensity is much reduced, but still their presence has been detected, though five miles of clear space have separated the two circuits.

Such effects have been known scientifically in the laboratory since the days of Faraday and of Henry, but it is only within the last few years that I have been able to utilize them practically through considerable distances. This has been rendered possible through the introduction of the telephone.

Last year (August, 1896) an effort was made to establish communication with the North Sandhead (Goodwin) Lightship. The apparatus used was designed and manufactured by Messrs. Evershed and Vignoles, and a most ingenious relay to establish a call invented by Mr. Evershed. One extremity of the cable was coiled in a ring on the bottom of the sea, embracing the whole area over which the lightship swept while swinging to the tide, and the other end was connected with the shore. The ship was surrounded above the water line with another coil. The two coils were separated by a mean distance of about 200 fathoms, but communication was found to be impracticable. The screening effect of the sea water and the effect of the iron hull of the ship absorbed practically all the energy of the currents in the coiled cable, and the effects on board, though perceptible, were very trifling—too minute for signaling. Previous experiments had failed to show the extremely rapid rate at which energy is absorbed with the depth or thickness of sea water. The energy is absorbed in forming eddy currents. There is no difficulty whatever in signaling through 15 fathoms. Speech by telephone has been maintained through 6 fathoms. Although this experiment has failed through water, it is thoroughly practical through air to considerable distances where it is possible to erect wires of similar length to the distance to be crossed on each side of the channel. It is not always possible, however, to do this, nor to get the requisite height to secure the best effect. It is impossible on a lightship and on rock light-houses. There are many small islands—Sark, for example—where it can not be done.

In July last Mr. Marconi brought to England a new plan. My plan is based entirely on utilizing electromagnetic waves of very low frequency. It depends essentially on the rise and fall of *currents* in the primary wire. Mr. Marconi utilizes electric or Hertzian waves of very high frequency, and they depend upon the rise and fall of electric force in a sphere or spheres. He has invented a new relay which, for sensitiveness and delicacy, exceeds all known electric apparatus.

The peculiarity of Mr. Marconi's system is that, apart from the ordinary connecting wires of the apparatus, conductors of very moderate length only are needed, and even these can be dispensed with if reflectors are used.

The transmitter.—His transmitter is Professor Righi's form of Hertz's radiator (fig. 2).

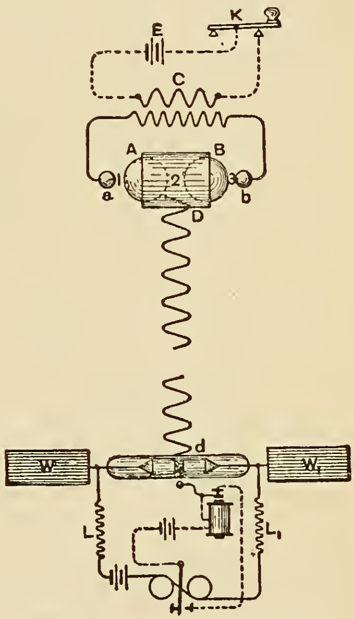

FIG. 2.—Diagram of the Marconi apparatus.

Two spheres of solid brass, 4 inches in diameter (A and B), are fixed in an oil-tight case D of insulating material, so that a hemisphere of each is exposed, the other hemisphere being immersed in a bath of vaseline oil. The use of oil has several advantages. It maintains the surfaces of the spheres electrically clean, avoiding the frequent polishing required by Hertz's exposed balls. It impresses on the waves excited by these spheres a uniform and constant form. It tends to reduce the wave lengths—Righi's waves are measured in centimeters, while Hertz's were measured in meters. For these reasons the distance at which effects are produced is increased. Mr. Marconi uses generally waves of about 120 centimeters long. Two small spheres, *a* and *b*, are fixed close to the large spheres, and connected each to one end of the secondary circuit of the "induction coil" C, the primary circuit of which is excited by a battery E, thrown in and out of circuit by the Morse key K. Now, whenever the key K is depressed sparks pass between 1, 2, and 3, and since the system A B contains capacity and electric inertia, oscillations are set up in it of extreme rapidity. The line of propagation is D *d*, and the frequency of oscillation is probably about 250 millions per second.

The distance at which effects are produced with such rapid oscillations depends chiefly on the energy in the discharge that passes. A 6-inch spark coil has sufficed through 1, 2, 3, up to 4 miles, but for greater distances we have used a more powerful coil—one emitting sparks 20 inches long. It may also be pointed out that this distance increases with the diameter of the spheres A and B, and it is nearly doubled by making the spheres solid instead of hollow.

The receiver.—Marconi's relay (fig. 2) consists of a small glass tube 4 centimeters long, into which two silver pole pieces are tightly fitted, separated from each other by about half a millimeter—a thin space which is filled up by a mixture of fine nickel and silver filings, mixed with a trace of mercury. The tube is exhausted to a vacuum of 4 millimeters, and sealed. It forms part of a circuit containing a local cell and a sensitive telegraph relay. In its normal condition the metallic powder is virtually an insulator. The particles lie higgledy-piggledy, anyhow, in disorder. They lightly touch each other in an irregular method, but when electric waves fall upon them they are "polarised," order is installed. They are marshaled in serried ranks, they are subject to pressure—in fact, as Prof. Oliver Lodge expresses it, they "cohere"—electrical contact ensues and a current passes. The resistance of such a space falls from infinity to about 5 ohms. The electric resistance of Marconi's relay—that is, the resistance of the thin disc of loose powder—is practically infinite when it is in its normal or disordered condition. It is then, in fact, an insulator. This resistance drops sometimes to 5 ohms, when the absorption of the electric waves by it is intense. It therefore becomes a conductor. It may be, as suggested by Professor Lodge, that we have in the measurement of the variable resistance of this instrument a means of determining the intensity of the energy falling upon it. This variation is being investigated both as regards the magnitude of the energy and the frequency of the incident waves. Now such electrical effects are well known. In 1866 Mr. S. A. Varley introduced a lightning protector constructed like the above tube, but made of boxwood and containing powdered carbon. It was fixed as a shunt to the instrument to be protected. It acted well, but it was subject to this coherence, which rendered the cure more troublesome than the disease, and its use had to be abandoned. The same action is very common in granulated carbon microphones like Hunning's, and shaking has to be resorted to to decohere the carbon particles to their normal state. M. E. Branly (1890) showed the effect with copper, aluminum, and iron filings. Prof. Oliver Lodge, who has done more than anyone else in England to illustrate and popularize the work of Hertz and his followers, has given the name "coherer" to this form of apparatus. Marconi "decoheres" by making the local current very rapidly vibrate a small hammer head against the glass tube, which it does effectually, and in doing so makes such a sound that reading Morse characters is easy. The same current that decoheres can also record Morse signals on paper by ink. The exhausted tube has two wings, which, by their size, tune the receiver to the transmitter by varying the capacity of the apparatus.[1] Choking coils prevent the energy escaping. The analogy to Prof. Silvanus Thompson's wave apparatus is evident. Oscillations set up in the transmitter fall

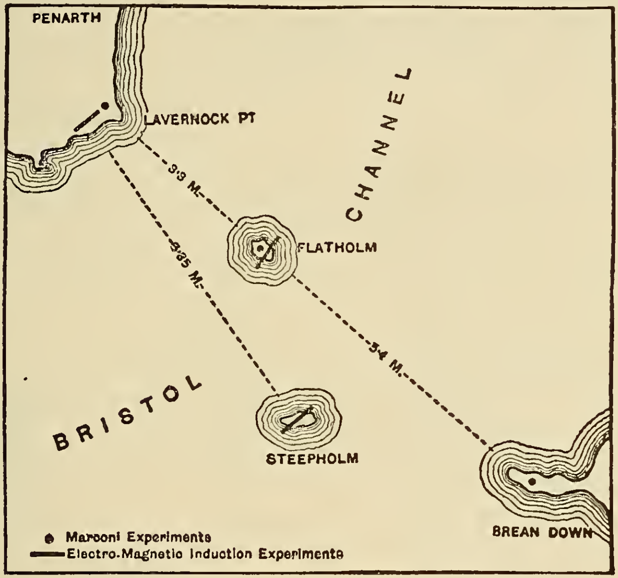

FIG. 3.—Map of locality where the experiments were carried out.

upon the receiver tuned in sympathy with it, coherence follows, currents are excited, and signals made.

In open clear spaces within sight of each other nothing more is wanted, but when obstacles intervene and great distances are in question, height is needed—tall masts, kites, and balloons have been used. Excellent signals have been transmitted between Penarth and Brean Down, near Weston-super-Mare, across the Bristol Channel, a distance of nearly 9 miles (fig. 3). (The system was here shown in operation.)

Mirrors also assist and intensify the effects. They were used in the earlier experiments, but they have been laid aside for the present, for they are not only expensive to make, but they occupy much time in manufacture.

[1] The period of vibration of a circuit is given by the equation $T=2\pi\sqrt{KL}$, so that we have simply to vary either the capacity K or the so-called "self induction" L to tune the receiver to any frequency. It is simpler to vary K.

It is curious that hills and apparent obstructions fail to obstruct. The reason is probably the fact that the lines of force escape these hills. When the ether is entangled in matter of different degrees of inductivity, the lines are curved, as in fact they are in light. Figure 4 shows how a hill is virtually bridged over by these lines, and consequently some electric waves fall on the relay. Weather seems to have no influence; rain, fogs, snow, and wind avail nothing.

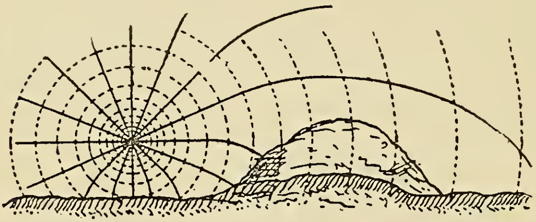

FIG. 4.—Diagram illustrating the way in which hills are bridged by the electric waves.

The wings shown in figure 2 may be removed. One pole can be connected with earth, and the other extended up to the top of the mast, or fastened to a balloon by means of a wire. The wire and balloon or kite, covered with tin foil, becomes the wing. In this case one pole of the transmitter must also be connected with earth. This is shown in figure 5.

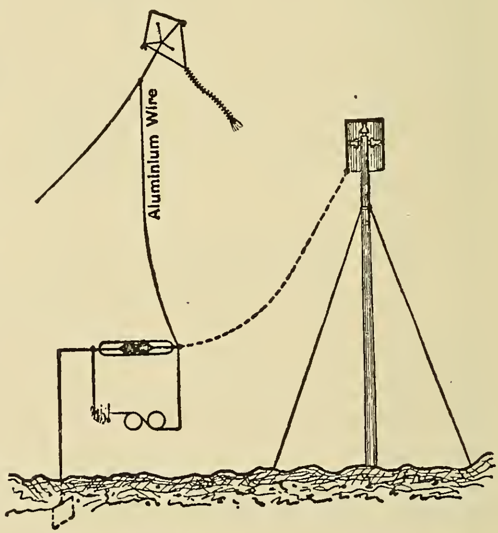

FIG. 5.—Diagram of Marconi connections when using pole or kite.

There are some apparent anomalies that have developed themselves during the experiments. Mr. Marconi finds that his relay acts even when it is placed in a perfectly closed metallic box. This is the fact that has given rise to the rumor that he can blow up an iron-clad ship. This might be true if he could plant his properly tuned receiver in the magazine of an enemy's ship. Many other funny things could be done if this were possible. I remember in my childhood that Captain Warner blew up a ship at a great distance off Brighton. How this was done was never known, for his secret died shortly afterwards with him. It certainly was not by means of Marconi's relay.

The distance to which signals have been sent is remarkable. On Salisbury Plain Mr. Marconi covered a distance of 4 miles. In the Bristol Channel this has been extended to over 8 miles, and we have by no means reached the limit. It is interesting to read the surmises of others. Half a mile was the wildest dream.[1]

It is easy to transmit many messages in any direction at the same time. It is only necessary to tune the transmitters and receivers to the same frequency or "note." I could show this here, but we are bothered by reflection from the walls. This does not happen in open space. Tuning is very easy. It is simply necessary to vary the capacity of the receiver, and this is done by increasing the length of the wings W in figure 2. The proper length is found experimentally close to the transmitter. It is practically impossible to do so far away.

It has been said that Mr. Marconi has done nothing new. He has not discovered any new rays; his transmitter is comparatively old; his receiver is based on Branly's coherer. Columbus did not invent the egg, but he showed how to make it stand on its end, and Marconi has produced from known means a new electric eye, more delicate than any known electrical instrument, and a new system of telegraphy that will reach places hitherto inaccessible. There are a great many practical points connected with this system that require to be threshed out in a practical manner before it can be placed on the market, but enough has been done to prove its value, and to show that for shipping and light-house purposes it will be a great and valuable acquisition.

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[1] "Unfortunately at present we can not detect the electro-magnetic waves more than 100 feet from their source."—Trowbridge, 1897, What is Electricity, p. 256.

"I mention 40 yards because that was one of the first out-of-door experiments, but I should think something more like half a mile was nearer the limit of sensibility. However, this is a rash statement not at present verified."—Oliver Dodge, 1894, The Work of Hertz, p. 18.

NOTE ON THE LIQUEFACTION OF HYDROGEN AND HELIUM.[1]

By Prof. JAMES DEWAR.

In a paper entitled "The liquefaction of air and research at low temperatures," read before the Chemical Society, and published in the Proceedings, No. 158, an account is given of the history of the liquid-hydrogen problem and the result of my own experiments up to the end of the year 1895. The facts are substantially as follows:

Wroblewski made the first conclusive experiments on the liquefaction of hydrogen in January, 1884. He found that the gas cooled in a capillary glass tube to the boiling point of oxygen, and expanded quickly from 100 to 1 atmospheres, showed the same appearance of sudden ebulition, lasting for a fraction of a second, as Cailletet had seen in his early oxygen experiments. No sooner had the announcement been made, than Olszewski confirmed the result by expanding hydrogen from 190 atmospheres, previously cooled to the temperature given by liquid oxygen and nitrogen evaporating under diminished pressure. Olszewski, however, declared in 1884 that he saw colorless drops, and by partial expansion to 40 atmospheres the liquid hydrogen was seen by him running down the tube. Wroblewski could not confirm Olszewski's results, his hydrogen being always obtained in the form of what he called a "liquide dynamique," or the appearance of an instantaneous froth. The following extract from Wroblewski's paper (Compt. rend., 1885, *100*, 981) states very clearly the results of his work on hydrogen:

"L'hydrogène soumis à la pression de 180 atmosphéres jusqu'à 190 atmosphères refroidi par l'azote bouillant dans la vide (à la température de sa solidification) et détendu brusquement sous la pression atmosphérique présente une mousse bien visible. De la couleur grise de cette mousse, où l'œil ne peut distinguer des gouttelettes incolores, on ne peut pas encore deviner quelle apparence aurait l'hydrogène à l'état de liquide statique et l'on est encore moins autorisé à préciser s'il à ou non une apparence métallique.

"J'ai pu placer dans cette mousse ma pile thermo-électrique et j'obtenu suivant les pressions employées des températures de —208°

[1]From Journal of the Chemical Society, London, No. CCCCXXVII, June, 1898. Vols. LXXIII and LXXIV, pp. 528-535.

jusqu'à −211° C. Je ne peux pas encore dire dans quelle relation se trouvent ces nombres avec la température réele de la mousse et la température d'ébullition de l'hydrogène sous la pression atmosphérique, puisque je n'ai pas encore la certitude que la faible durée de ce phénomène ait permis à le pile de se refroidir complètement. Néanmoins je crois aujourd'hui de mon devoir de publier ces résultats, afin de préciser l'état actuel de la question de la liquéfaction de l'hydrogène."

It is well to note that the lowest thermo-electric temperature recorded by Wroblewski during the adiabatic expansion of the hydrogen, namely, −211°, is really equivalent to a much lower temperature on the gas thermometer scale. The most probable value is −230°, and this must be regarded as the highest temperature of the liquid state, or the critical point of hydrogen according to his observations. The above methods having failed to produce "static" hydrogen, Wroblewski suggested that the result might be attained by the use of hydrogen gas as a cooling agent. From this time until his death in the year 1888 Wroblewski devoted his time to a laborious research on the isothermals of hydrogen at low temperatures. The data thus arrived at enabled him, by the use of Van der Waal's formulæ, to calculate the critical constants and boiling point of liquid hydrogen.

Olszewski returned to the subject in 1891, repeating and correcting his old experiments of 1884, which Wroblewski had failed to confirm, in a glass tube 7 millimeters in diameter instead of one of 2 millimeters, as in the early trials. He says, "On repeating my former experiments I had no hope of obtaining a lower temperature by means of any cooling agent, but I hoped that the expansion of hydrogen would be more efficacious, on account of the larger scale on which the experiment was made." The result of these experiments Olszewski describes as follows: "The phenomenon of hydrogen ebullition, which was then observed, was much more marked and much longer than during my former investigations in the same direction. *But even then I could not perceive any meniscus of liquid hydrogen.*" Further, "The reason for which it has not been hitherto possible to liquify hydrogen in a static state is that there exists no gas having a density between those of hydrogen and of nitrogen, and which might be, for instance, 7–10 (H 1). Such a gas could be liquefied by means of liquid oxygen or air as cooling agent and be afterwards used as a frigorific menstruum in the liquefaction of hydrogen."

Professor Olszewski in 1895 determined the temperature reached in the momentary adiabatic expansion of hydrogen at low temperatures just as Wroblewski had done in 1885, only he employed a platinum resistance thermometer instead of a thermo-junction.

For this purpose he used a small steel bottle of 20 or 30 cubic centimeters capacity, containing a platinum resistance thermometer. In this way temperatures were registered which were regarded as those of the critical and boiling points of liquid hydrogen, a substance which could not be seen under the circumstances, and was only assumed at the most to exist for a second or two during the expansion of the gaseous hydrogen in the small steel bottle.

The results arrived at by Wroblewski and Olszewski are given in the following table:

	Wroblewski, 1885.	Olszewski, 1895.
Critical temperature...	−240°	−234°
Boiling point..........	−250°	−243°
Critical pressure.......	13 at.	20 at.

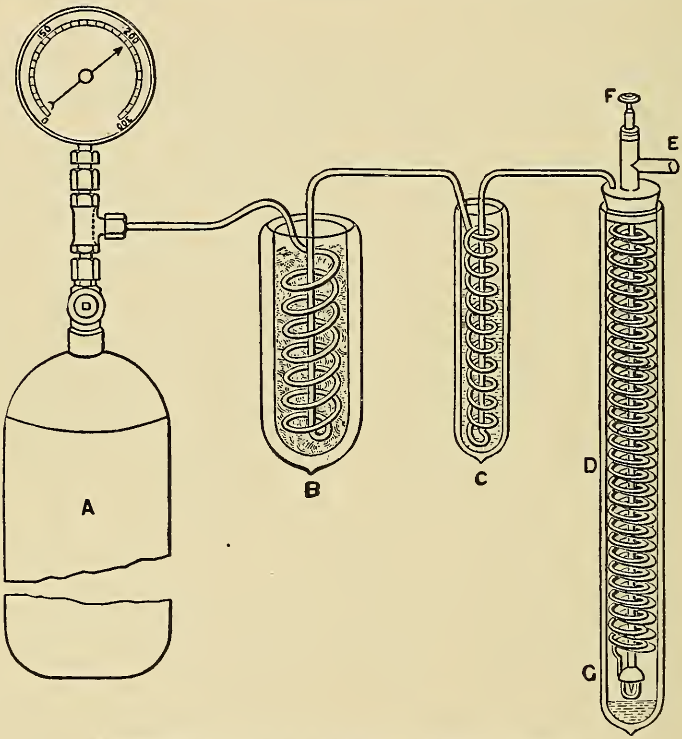
The moment the critical point is approximately defined the boiling point is roughly known, and the critical pressure can be inferred from analogy with the behavior of other substances.

In a paper published in the Philosophical Magazine, September, 1884, "On the liquefaction of oxygen and the critical volumes of fluids," the suggestion was made that the critical pressure of hydrogen was wrong, and that instead of being 99 atmospheres (as deduced by Sarrau from Amagat's isothermals), the gas had probably an abnormally low value for this constant. This view was substantially confirmed by Wroblewski finding a critical pressure of 13.3 atmospheres, or about one-fourth of that of oxygen. The Chemical News (Sept. 7, 1894) contains an account of the stage the author's hydrogen experiments had reached at that date. The object was to collect liquid hydrogen at its boiling point, in an open vacuum vessel, which is a much more difficult problem than seeing the liquid in a glass tube under pressure and at a higher temperature. In order to raise the critical point of hydrogen to about −200°, from 2 to 5 per cent of nitrogen or air was mixed with it. This is simply making an artificial gas containing a large proportion of hydrogen which is capable of liquefaction by the use of liquid air. The results are summed up in the following extract from the paper: "One thing can, however, be proved by the use of the gaseous mixture of hydrogen and nitrogen, namely, that by subjecting it to a high compression at a temperature of −200° and expanding the resulting liquid into air, a much lower temperature than anything that has been recorded up to the present time can be reached. This is proved by the fact that such a mixed gas gives, under the conditions, a paste or jelly of solid nitrogen, evidently giving off hydrogen, because the gas coming off burns fiercely. Even when hydrogen containing only some 2 to 5 per cent of air is similarly treated, the result is a white solid matter (solid air) along with a clear liquid of low density, which is so exceedingly volatile that no known device for collecting has been successful."

The report of a Friday evening lecture on New Researches on Liquid Air[1] contains a drawing of the apparatus employed for the production

[1] Proc. Roy. Inst., 1896.

of a jet of hydrogen containing visible liquid. This is reproduced in the figure. A represents one of the hydrogen cylinders; B and C, vacuum vessels containing carbonic acid under exhaustion and liquid air, respectively; D is the coil, G the pin-hole nozzle, and F the valve. By means of this jet, liquid air can be quickly transformed into a hard solid. It was shown that such a jet could be used to cool bodies below the temperature that it is possible to reach by the use of liquid air, but all attempts to collect the liquid hydrogen from the jet in vacuum vessels failed. No other investigator has, so far, improved on the



Apparatus used in the production of the liquid hydrogen jet.

results the author described in the Proceedings of the Chemical Society (No. 158), 1895, or, indeed, touched the subject since that date. The type of apparatus used in these experiments worked well, so it was resolved to construct a much larger liquid-air plant, and to combine with it circuits and arrangements for the liquefaction of hydrogen, which will be described in a subsequent paper. This apparatus took a year to build up, and many months have been occupied in testing and making preliminary trials. The many failures and defeats need not be detailed.

On May 10 of this year, starting with hydrogen cooled to —205°, and under a pressure of 180 atmospheres, escaping continuously from the nozzle of a coil of pipe at the rate of about 10 or 15 cubic feet per minute, in a vacuum vessel doubly silvered and of special construction, all surrounded with a space kept below —200°, liquid hydrogen commenced to drop from this vacuum vessel into another doubly isolated by being surrounded by a third vacuum vessel. In about five minutes 20 cubic centimeters of liquid hydrogen were collected, when the hydrogen jet froze up, from the accumulation of air in the pipes frozen out from the impure hydrogen. The yield of liquid was about 1 per cent of the gas. The hydrogen in the liquid condition is clear and colorless, showing no absorption spectrum, and the meniscus is as well defined as in the case of liquid air. The liquid must have a relatively high refractive index and dispersion, and the density appears also to be in excess of the theoretical density, namely, 0.18 to 0.12, which we deduce respectively from the atomic volume of organic compounds, and the limiting density found by Amagat for hydrogen gas under infinite compression. Yet this may be a delusion due to its high dispersion. A preliminary attempt to weigh a small glass bulb in the liquid made the density about 0.08. My old experiments on the density of hydrogen in palladium gave a value for the combined element of 0.62, and it will be interesting to find the accurate density of the liquid substance at its boiling point. Not having arrangements at hand to determine the boiling point, other than a thermo-junction which gave entirely fallacious results, experiments were made to prove the excessively low temperature of the boiling fluid. In the first place, if a long piece of glass tubing, sealed at one end and open to the air at the other, is cooled by immersing the closed end in the liquid hydrogen, the tube immediately fills, where it is cooled, with solid air; a small tube containing liquid oxygen became a bluish solid. A first trial of putting the liquid hydrogen under exhaustion gave no appearance of transition into the solid state. The liquid hydrogen in its vacuum tube, which is immersed in liquid air so that the external wall of the vacuum vessel is maintained at about —190°, is found to evaporate at a rate not far removed from that of liquid air from a similar vacuum vessel under the ordinary conditions of storage. This leads me to the conclusion that with proper isolation it will be possible to manipulate with liquid hydrogen as easily as with liquid air. The second experiment was made with a tube containing helium.

The Cracow Academy Bulletin for 1896 contains a paper by Professor Olszewski, entitled "A research on the liquefaction of helium," in which he states, "As far as my experiments go, helium remains a permanent gas and apparently is much more difficult to liquefy than hydrogen." In a paper of my own in the proceedings of the Chemical Society, No. 183 (1896–97), in which the separation of helium from Bath gas was effected by a liquefaction method, the suggestion was made that the volatility of hydrogen and helium would probably be found close together, just like those of fluorine and oxygen. Having a specimen of purified helium, which had been extracted from Bath gas, sealed up in a bulb with a narrow tube attached, the latter was placed in liquid hydrogen, when a distinct liquid was seen to condense. The same experiment repeated, only using liquid air evaporating in a vacuum, gave no trace of condensation. From this result it would appear that there can not be any great difference between the boiling points of helium and hydrogen.

All known gases have now been condensed into liquids which can be manipulated at their boiling points under atmospheric pressure in suitably arranged vacuum vessels. With hydrogen as a cooling agent we shall get within 20 or 30 of the zero of absolute temperature, and its use will open up an entirely new field of scientific inquiry. Even as great a man as James Clerk Maxwell had doubts as to the possibility of ever liquefying hydrogen. (See Scientific Papers 2, 412.) In concluding his lectures on the non metallic elements, delivered at the Royal Institution in 1852 and published the following year, Faraday said:[1]

"There is reason to believe we should derive much information as to the intimate nature of these nonmetallic elements if we could succeed in obtaining hydrogen and nitrogen in the liquid or solid form. Many gases have been liquefied; the carbonic acid gas has been solidified, but hydrogen and nitrogen have resisted all our efforts of the kind. Hydrogen in many of its relations acts as though it were a metal; could it be obtained in a liquid or solid condition the doubt might be settled. This great problem, however, has yet to be solved; nor should we look with hopelessness on this solution when we reflect with wonder—and as I do almost with fear and trembling—on the powers of investigating the hidden qualities of these elements—of questioning them, making them disclose their secrets and tell their tales—given by the Almighty to man."

Faraday's expressed faith in the potentialities of experimental inquiry in 1852 has been justified forty-six years afterwards by the production of liquid hydrogen in the very laboratory in which all his epoch-making researches were executed. The "doubt" has now been settled; hydrogen does not possess in the liquid state the characteristics of a metal. No one can predict the properties of matter near the zero of temperature. Faraday liquefied chlorine in the year 1823. Sixty years afterwards Wroblewski and Olszewski produced liquid air, and now, after a fifteen years' interval, the remaining gases, hydrogen and helium, appear as static liquids. Considering the step from the liquefaction of air to that of hydrogen is relatively as great in the thermodynamic sense as that from liquid chlorine to liquid air, the fact that the former result has been achieved in one-fourth the time needed to accomplish the latter proves the greatly accelerated race of scientific progress in our time.

The efficient cultivation of this field of research depends upon combination and assistance of an exceptional kind, but in the first instance money must be available, and the members of the Royal Institution

[1] See Faraday's "Lectures on the nonmetallic elements," pp. 292–293.

deserve my especial gratitude for their handsome donations to the conduct of this research. Unfortunately, its prosecution will demand a further large expenditure. It is my duty also to acknowledge that at an early stage of the inquiry the honorable company of Goldsmiths helped low temperatures investigation by a generous donation to the research fund.

During the whole course of the low temperature work, carried out at the Royal Institution, the invaluable aid of Mr. Robert Lennox has been at my disposal, and it is not too much to say that but for his engineering skill, manipulative ability, and loyal perseverance the present successful issue might have been indefinitely delayed. My thanks are also due to Mr. J. W. Heath for valuable assistance in the conduct of these experiments.

ADDENDUM.

Since the above paper was written, both the boiling point and specific gravity of hydrogen have been determined. The boiling point in the meantime given by the use of a platinum resistance thermometer involves, however, extrapolation of the curve correlating temperature and resistance. The result is that the boiling point of hydrogen is minus 228° C. or 35° absolute. At this temperature, the tension of liquid air (which, of course, becomes solid) is less than 0.002 millimeter. The resistance of the thermometer used was 5.338 ohm at the melting point of ice, and this was reduced to 0.129 ohms when placed in boiling hydrogen. The absolute zero in platinum degrees of this thermometer was minus 263.27°, and the temperature measured on this scale is minus 256.29° or 6.38° from the point where the conductivity of the platinum would become infinite. The resistance of the platinum in the liquid hydrogen is reduced to nearly one-eleventh of what it is in liquid oxygen. It will be necessary to find out the electric conductivity of the fluid itself, and to repeat the observations with other thermometers before we can arrive at more definite conclusions. The vapor of hydrogen at its boiling point is about eight times denser than the gas at ordinary temperatures, or it has about half the density of air, while the vapor coming off from liquid air at its boiling point is somewhat less than four times the density of air at the ordinary temperature. By evaporation in a vacuum, the temperature of liquid hydrogen will be lowered from 10° to 15°, but it will be practically impossible (so far as we can anticipate the results of experiment) to reach a lower temperature than minus 250° C. or 20° absolute by this means. At present we can see no way of bridging over the last 20° or 25°, and therefore the approach to the zero of absolute temperature and the study of matter and energy under such conditions must be confined to temperatures above 25° absolute.

The density of liquid hydrogen has been approximately determined by evaporating some 10 cubic centimeters of the liquid, and collecting and measuring the gas produced, thereby ascertaining its weight. In this way 8.15 liters at 14° C. and 753 millimeters were collected over water from between 9 and 10 cubic centimeters of liquid hydrogen. It appears, therefore, that the density of the liquid is about 0.07, using whole numbers as the calculation works out to 0.068 nearly. Liquid hydrogen is therefore a very deceptive fluid so far as appearance goes. The fact of its collecting so easily, dropping so well, and having such a well-defined meniscus induced me to believe that the density might be about half that of liquid air. It was a great surprise to find the density only one-fourteenth of water. Liquid marsh gas was the lightest known liquid, the density at its boiling point being 0.417, but liquid hydrogen has only one-sixth the density of this substance. The density of occluded hydrogen in palladium being 0.62, it is eight times denser than the liquid.

Hydrogen in the liquid state is one hundred times denser than the vapor it is giving off at its boiling point, whereas liquid oxygen is two hundred and fifty-five times denser than its vapor. It appears, therefore, that the atomic volume of liquid hydrogen at its boiling point is 14.3, as compared with 13.7 for oxygen under similar circumstances. In other words, they are nearly identical. From this we can infer that the critical pressure need not exceed 15 atmospheres. The extraordinary properties theory requires hydrogen should possess, especially as regards specific and latent heat, become more intelligible from the moment we know that the density is so small. In other words, when we compare the properties of equal volumes of liquid hydrogen and air under similar corresponding temperatures, they do not differ more than might be anticipated.

THE RECENTLY DISCOVERED GASES AND THEIR RELATION TO THE PERIODIC LAW.[1]

By William Ramsay.

Gentlemen: It is well known to you all how the remarkable observation of Lord Rayleigh that nitrogen from the atmosphere possesses a greater density than that prepared from ammonia or nitrates led to the discovery of argon, a new constituent of the air. I need not say that had it not been for this observation the investigations of which I shall speak this evening would never have been carried out, at least not by me. You also, doubtless, will remember that the search for some compound of argon was rewarded, not by the attainment of the quest, but by the discovery, in clèveite and other rare uranium minerals, of helium, an element whose existence in the chromosphere of the sun had already been suspected. And, further, I hardly need to recall to your minds that the density of helium is in round numbers 2, and that of argon 20, and that the ratio of specific heats of both these gases, unlike that of most others, is 1.66.

From these figures it follows that the atomic weight of helium is 4 and that of argon 40. It is true that in many quarters this conclusion is not admitted, but I have always thought it better to recognize the validity of the theory of gases and accept the logical deductions than to deny the truth of the present theories. The only reason for not admitting the correctness of these atomic weights is that that of argon is greater than that of potassium, but this is no severer attack upon the validity of the periodic law than the accepted position of iodin after, instead of before, tellurium. As a matter of fact, all the more recent determinations of the atomic weight of tellurium give the figure 127.6, while that of iodin remains unchanged at 127.

Since these new elements form no compounds, it is not possible to decide the question by purely chemical methods. Were it only possible for us to propare a single volatile compound of helium or of argon our problem would be solved. In spite of many attempts, I have not been

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able to confirm Berthelot's results with benzine or carbon bisulfid. I have, however, offered to place a liter of argon at the disposal of my distinguished colleague, that he may repeat his experiments on a larger scale. No one can doubt that it is exceedingly desirable that the question of these atomic weights should be finally decided, and that by chemical methods.

In order that the subject may not depend wholly on physical theories, I have considered it from another standpoint. If we assume, as from countless chemical facts we are fully justified in doing, that the periodic law is true, then, giving helium the atomic weight 2 and argon 20, there is no possible place for an element of their mean atomic weight; for, unless we absolutely overturn the accepted views, there is no vacancy in the table for such an element. This appears from the following portion of the table:

H = 1 He = 2(?) Li = 7 Gl = 9.2 B = 11 C = 12 N = 14 O = 16
F = 19 A = 20(?)

It is true there is space enough between He = 2 and Li = 7, but it is highly improbable that an element belonging to the argon series could have so low an atomic weight. The difference between adjacent members of the same group of elements is generally from 16 to 18 units, but here such a difference is wholly excluded. If, on the other hand, we assume He = 4 and A = 40, it would be, in my opinion, by no means improbable that such an element could exist whose atomic weight would be somewhere about 16 units greater than that of helium, and consequently 20 units less than that of argon. The discovery of such an element would be, therefore, not only a proof of the correctness of 40 as the atomic weight of argon, but also a confirmation of the present views regarding the significance of the specific heats of gases for their molecular weight.

A glance at the periodic table will make these considerations clear, for in the latter case we have the following series:

Li=7	Gl=9.2	B=11	C=12	N=14
Na=23	Mg=24.3	Al=27	Si=28	P=31
				He=4
		O=16	F=19	(?)=20
		S=32	Cl=35.5	A=40

Shortly after the discovery of helium I began the search for this suspected element of atomic weight of about 20, at first in connection with Doctor Collie, my former assistant, and later with my present assistant, Doctor Travers.

At first it appeared not improbable that this element might be found in those uranium minerals from which helium had been obtained. We did not, however, confine ourselves to these minerals, but tested all available metals, either by heating in a vacuum or by fusion with sodium bisulphate. In many of these minerals helium was found; in many, on the other hand, only traces of hydrocarbons and hydrogen. One mineral only, malakon, gave sufficient argon to be recognizable by the spectroscope; the others which contained helium gave off generally also a trace of argon, as was later shown by our diffusion experiments. Naturally it was impossible to be certain that the few cubic centimeters of gas which we collected from these minerals contained no new gas, but we failed to detect the presence of any new lines with the spectroscope.

You will, undoubtedly, recall that soon after the discovery of helium doubts were expressed in many quarters as to whether the gas was really uniform or a mixture. In order to dispel these doubts, and also to search for the missing gas, Doctor Collie and I carried out a long series of diffusion experiments. Through these we reached the conclusion that it was, in fact, possible to separate helium into two constituents, one of which possessed a somewhat higher density than the other. Later experiments, however, in conjunction with Doctor Travers, showed that this conclusion was erroneous. In this second series much larger quantities of helium were at our disposal, and, to our disappointment, we found that the heavier fractions of our gas owed their greater density to the presence of a trace of argon. Here, again, we were unable to find any new line in the spectrum, and thus far our search was fruitless.

We next directed our attention to meteorites and to mineral waters. Only one out of seven meteorites examined by Dr. Travers and myself showed the presence of helium and with it a trace of argon; the others gave only hydrogen and hydrocarbons, which were also present in the gases from the meteorite which contained helium and argon. Here, again, our search was in vain. The mineral water from Bath has been investigated by Lord Rayleigh; in the waters from Cantarets, in the Pyrenees, Dr. Schlösing has found both argon and helium. Dr. Travers and I examined these gases for new lines, but, as before, none were found.

Our patience was now well-nigh exhausted. There seemed, however, to be a single ray of hope left, in an observation which had been made by Dr. Collie and myself. You will recall that the atomic weight of argon was apparently too high; at all events it would be more in harmony with the periodic law if the density of argon were 19 instead of 20, and hence its atomic weight 38 instead of 40. Hence, after some fruitless attempts to separate argon into more than one constituent by means of solution in water, we undertook a systematic diffusion of argon. We did not, however, carry this procedure very far, for, at that time, we believed that helium was a more probable source of the desired gas; nevertheless, we found a slight difference in density between the gas which diffused first and that which remained undiffused. We, therefore, decided to prepare a large quantity of argon, and, after liquefying it, to investigate carefully the different fractions on distillation.

Such an operation demands much time. In the first place, the necessary apparatus is not to be found in any ordinary chemical laboratory; the preparation can not be carried out in glass tubes in an ordinary furnace, but requires iron tubes of large size and an especial furnace; in the second place, the operation must be repeated several times, for it is not convenient to work with an excessively large quantity of magnesium. As before, we removed the oxygen from the air by means of copper at a red heat; the atmospheric nitrogen remaining was collected in a large gasometer holding about 200 liters; after drying over concentrated sulphuric acid and phosphorous pentoxid, the gas was passed through an iron tube of 5 centimeters diameter filled with magnesium filings; the gas was then passed through a second copper oxid tube to remove the hydrogen; it then entered a galvanized-iron gasometer, which was constructed like an ordinary illuminating-gas gasometer, in order that the argon should come in contact with as little water as possible, since argon is quite appreciably soluble in water, and, had the ordinary form of gasometer been used, much would have been lost in this way. Again, the gas had to be led over hot magnesium to reduce still further the quantity of nitrogen; and, at last, it was circulated between the gasometers, passing on its way through a mixture of thoroughly heated lime and magnesia at a red heat. This is a means of absorption, recommended by Maquenne, to remove the last of nitrogen. Since, however, it is not possible to dry the lime absolutely, hydrogen is taken up by the gas, and this must again be removed by copper oxid, in order that all the hydrogen may be burned, after which the water must again be removed by drying tubes.

These operations required several months and were chiefly directed by Dr. Travers.

Meanwhile, it seemed to be worth while to make an examination as to whether the desired gas might possibly form compounds and be united with the magnesium, by which the nitrogen had been removed. Miss Emily Aston assisted me to settle this question.

Some 700 grams of the magnesium nitrid were, for this purpose, treated with water in a large exhausted flask, in such a manner that the evolved ammonia was absorbed in dilute sulphuric acid which had been thoroughly boiled; all the other gases were collected by a Töpler pump. The total volume of this gas was hardly 50 cubic centimeters; it proved to be chiefly hydrogen, with a trace of hydrocarbons, arising from the small quantity of metallic magnesium present in the magnesium nitrid. After the hydrogen had been removed by explosion, an excess of oxygen was passed into the tube and the nitrogen removed in the usual manner by sparking over alkali. The presence of nitrogen here was undoubtedly due to the impossibility of perfectly exhausting all the air from so large a flask; the volume of nitrogen was about 10 cubic centimeters. There now remained but a minute bubble of gas, and on transferring this to a vacuum tube at very low pressure the spectrum of argon appeared. There was here, therefore, no trace of a new gas to be found.

It was not deemed worth while to investigate the ammonia, since I had already prepared nitrogen out of this and Lord Rayleigh had determined its density; he found this to be exactly the same as the density of nitrogen from different chemical sources. It remained, however, possible that the sought-for gas could combine with hydrogen, and that such a compound might possess an acid character; in this case it might have entered into combination with the magnesium. On account of the possibility that such a compound might be soluble, the magnesia was extracted with water, the solution evaporated and treated with sulphuric acid in a vacuum. A gas was evolved, but it proved to be exclusively carbon dioxid. We should have carried the treatment of the magnesium further had not the argon at last become sufficiently pure to subject it to the refrigerating action of liquid air, and it seemed to me there was more hope of finding the new substance in the argon from the atmosphere than in this residue of magnesia, which it would require much time and labor to work up.

Dr. Hampson, the inventor of a very simple and practical machine for the preparation of liquid air, which is based upon the same principle as that of Herr Linde, was so kind as to place large quantities of liquid air at my disposal. In order to become acquainted with the art of working with so unusual a material, I asked Dr. Hampson for a liter; with this Dr. Travers and I practiced and made different little experiments to prepare ourselves for the great experiment of liquefying argon.

It seemed to me a pity to boil away all the air without collecting the last residue; for, though it seemed improbable that the looked-for element could be here, yet it was, indeed, possible that a heavier gas might accompany the argon. This suspicion was confirmed. The residue from the liquid air consisted chiefly of oxygen and argon, and, after removing the oxygen and nitrogen, beside the spectrum of argon were two brilliant lines, one in the yellow, which was not identical with D_3 of helium, and one in the green. This gas was decidedly heavier than argon; its density was 22.5 instead of the 20 of argon. We had, therefore, discovered a new body, which was an element, for the ratio between the specific heats was 1.66. To this element we gave the name "krypton." Up to this time we have not followed further the study of this element; we have, however, collected and preserved many residues which are rich in krypton. It was, however, our first intention to examine the lightest part of the argon. In many, however, we remarked, in passing, that the wave-length of the green line of krypton is exceedingly close to that of the northern lights, being 5,570, while the latter is 5,571.

Our whole supply of argon was now liquefied in the following manner: The gasometer containing the argon was connected with a series of tubes in which the gas passed over respectively hot copper oxid, concentrated sulphuric acid, and phosphorus pentoxid; it then passed by a two-way cock into a small flask, holding about 30 cubic centimeters, which was inclosed in a Dewar tube. By means of the other opening of the cock, the flask was connected with a mercury gasometer. By means of a U-shaped capillary and mercury trough, it was also possible, through a three-way cock, to collect the gas at will in glass tubes. About 50 cubic centimeters of liquid air were poured into the double walled tube, and, by means of a Fleuss air pump kept constantly in action, the liquid air boiled at 10 to 15 millimeters pressure. The argon liquefied rapidly as soon as subjected to this low temperature, and in the course of half an hour it was completely condensed. Altogether there were about 25 cubic centimeters of a clear, limpid, colorless liquid, in which floated white flakes of a solid substance. By stopping the pump the pressure over the liquid air was now increased, and the argon boiled quietly, the first portions of the gas being collected in the mercury gasometer. Changing now the three-way cock, the largest portion of the argon passed back into the iron gasometer; after nearly all the liquid had boiled away and only the solid substance was left in the flask, the last portions of the gas were collected separately. The solid substance remained persistently in the flask; it was slowly volatilized by means of a Töpler pump, which stood in connection with the apparatus.

We first directed our attention to the lighter fractions, for these had for us the greatest interest. The density of this gas was found to be 14.67; the ratio between the specific heats was as usual 1.66, and the spectrum showed, beside the well-known groupings of argon, a large number of red, orange, and yellow lines of varying intensity. Evidently we had before us a new element, which was contaminated with argon.

This gas was then liquefied in a similar apparatus to that first used, but constructed on a smaller scale; a portion, however, remained uncondensed. Even by raising the reservoir of the mercury gasometer until an overpressure of an atmosphere was reached, it was impossible to convert all the gas into a liquid, although the temperature of the boiling air was reduced as low as possible by rapid pumping. By repeated raising and lowering of the reservoir we finally passed all the gas through the cooled space, in order to free it, as far as possible, from argon. The uncondensible gas was collected by itself, and the remainder was evaporated into another gasometer.

You can well imagine how eager we were to know what the density of this purified gas would prove to be. It was immediately weighed. Our satisfaction can well be realized when we found that its density was 9.76. Since, however, its spectrum at low pressure still showed argon lines, though weak, we were compelled to admit that this number was certainly too high. It was impossible that this gas should not contain argon, since at the temperature used argon possessed a measurable vapor pressure.

We have, therefore, estimated that the density of the pure gas is 9.65. Here our work for the time was ended by the beginning of the summer holidays.

On our return we resumed the study of this gas, which we will hereafter designate by its name of "neon." Its spectrum was photographed by Mr. Baly, one of my assistants, by means of a spectrometer which we had constructed during the vacation. To our astonishment, the lines of helium were easily recognized. A comparison photograph showed this beyond all question. Hence the density of the gas was in all probability too low, owing to the presence of the helium. Since now the temperature used was insufficient to liquify the neon, and since the argon had been removed as far as possible, we had to face the problem of how one could free neon from its accompanying impurities. A means was found in its solubility. It is well known that the solubility of those gases which do not react chemically with the solvent follows in general the same order as their condensibility. According to this helium should have a lesser solubility than neon, and neon than argon. The solubility of these gases in water is, however, too slight to be available for their separation. We have, therefore, used liquid oxygen as a solvent. This mixes with all three gases and boils at a temperature not far from the boiling point of argon. We therefore mixed the gas with sufficient oxygen to be almost wholly condensed at the temperature attained by boiling air at the lowest possible pressure. The uncondensed portion, about one-fifth of the whole, was separated and collected as that richest in helium; the middle portion we considered as purified neon, while the remainder consisted of a mixture of argon and neon; naturally, all these portions contained oxygen in larger or smaller quantities.

After the removal of the oxygen, which was accomplished by passage over hot copper filings, we determined the density and refractivity of the middle portion. The density in two determinations was 10.04 and 10.19; the second figure was obtained after passing the electric spark through the gas mixed with oxygen in the presence of caustic potash and subsequent removal of the oxygen by phosphorus. The entire quantity weighed was only 30 cubic centimeters at a pressure of 250 millimeters. The weight was 0.0095 gram. I mention these figures in order to show with what an exceedingly small quantity of gas it is possible to carry out a very satisfactory density determination.

The refractivity of this portion with reference to the air as unity was 0.338. This portion still showed the spectra of argon and helium, and was, therefore, submitted to a second purification, in which the heavier part was more completely removed than the lighter. Even this purification, however, did not remove all the argon, but its quantity was decidedly diminished. The density was somewhat diminished, and helium was stronger in the spectrum. The entire amount of neon had become, by these operations, so divided up that it was not possible to carry out a further purification without preparing a greater quantity of crude neon. On this Dr. Travers and I are at present engaged.

In the meantime Mr. Baly has made exact measurements of the lines of the neon spectrum, at the same time eliminating all the lines which belong to argon and to helium by superposed plates. The values were compared with iron lines photographed upon the same plate, and the measurements were carried out by means of different pairs of these known lines. The most important lines are the following:

Most important lines of the new spectrum.

Red.	Red.	Red.	Yellow (D_5).	Green.	Blue.
6402	6267	6096	5853	5401	*4716
6383	6218	6074		5341	4722
6335	6164	6030		5331	4710
	6143				4709
					4704

* The third figure in this number is probably a misprint (Tr).

Up to the present we have had little time to study thoroughly the other companion of argon in the atmosphere. Dr. Travers and I have, however, worked upon it. The heavier fraction of the air contains three gases, one of which appears very perplexing. We have named it "metargon." This gas remains, mixed with excess of argon, after the evaporation of liquid air or argon. Up to this time we have not succeeded in obtaining it in a condition free from argon. Its peculiarity is that when it is mixed with oxygen and subjected to the influence of the electric spark in presence of caustic potash it shows constantly the "Swan-spectrum" as of carbon monoxid. We have treated a mixture of carbon monoxid and argon in a similar way, and, after fifteen minutes sparking, all the carbon had disappeared; in a Plücker tube no trace of the carbon spectrum could be recognized. I will, however, not yet venture to express an opinion as to the nature of this gas. It needs further investigation, and for this at present we have no time.

As regards krypton, which is distinguished by three brilliant lines, one in red, one in yellow and one in green, we are in much the same position. We have collected a considerable quantity of the impure gas, which shows the spectrum finely, although that of argon is also present. We hope that we shall soon be able to pursue this portion of our work further. We can merely note here that the specific gravity of the gas which shows this spectrum in such a marked way is not far different from that of argon.

The heaviest of these gases we have weighed, although in impure condition. Its density is 32.5. I need not call your attention to the fact that there is space for an element of the helium group between bromin and rubidium. Such an element should have an atomic weight of 81 to 83, which corresponds to a density of 40.5 to 41.5, under the very probable supposition that, like the other gases of this group, it is monatomic. The spectrum of this gas, which we have named "xenon"—the stranger—has many lines; none of these are of marked intensity, and in this respect the spectrum resembles somewhat that of argon. It is also analogous to argon in another particular, that the spectrum undergoes a remarkable change when a Leyden jar is put into the circuit. As with argon, many new blue and green lines appear, while other lines, mostly in the red, either disappear or lose much of their intensity. Further than this we have not proceeded in studying xenon; for our attenton has been given chiefly to neon, as well as to a problem regarding argon.

We have repeatedly met the question: "Are the properties of argon not appreciably changed by the presence of this new gas?" In order to settle this question we have fractioned 25 cubic centimeters of liquid argon several times and have collected separately about 200 cubic centimeters of the lightest and as much of the heaviest fraction. This operation was repeated three times By this means we hoped to have removed the greatest part of the neon, krypton, metargon, and xenon. Then we liquefied the argon a fourth time, and as it boiled away collected six samples, each after one-fifth of the whole quantity had evaporated. These samples were carefully purified and weighed. The density referred to 0=16 and the refractivity to air =1 are as follows:

Fraction.	Density.	Refractivity.
First	19.65	0.962
Second.....	19.95	0.969
Third......	19.95	....
Fourth	*19.91	....
Fifth	19.97	0.968
Sixth	19.95	0.966

*Contained nitrogen.

The first fraction possesses, as appears from the table, a lower density and also a lower refractivity. The other fractions vary very little from each other. Since these determinations were made by using only 30 cubic centimeters, we have weighed 160 cubic centimeters of the fifth and sixth fractions. The first determined density of the fifth fraction was 19.935, but at a pressure of 5 millimeters the spectrum of nitrogen was easily recognizable in a Plücker tube. After the gas had been again purified by sparking, until all the nitrogen had been removed, the density was 19.957. In two experiments the fourth fraction of gas gave 19.952 and 19.961. We must then accept the true density of argon as not far from 19.96. Independently Lord Rayleigh and I found the density of argon to be 19.94; so it is clear that the impurities of neon and the heavier gases have little influence. The somewhat greater density of pure argon arises from the fact that the neon, which is the chief impurity present, has been removed; the influence of the other gases can not be recognized, owing to the insignificant quantities present. In fact, in 15 liters of argon we found no appreciable trace of xenon; it can be prepared only out of large quantities of liquid air.

I must take this opportunity of thanking you most sincerely for the honor you have done me in inviting me to deliver this address. It has been said by some scientist that the greatest joy of life lies in discovering something which is new. There is, however, another joy almost equally great, that of making known the results of an investigation to one's fellow-scientists. This joy, my friends, you have given me to an extreme degree, and for this I express to you my warmest thanks.

THE KINETIC THEORY OF GASES AND SOME OF ITS CONSEQUENCES.[1]

By WILLIAM RAMSAY.

"Flower in the crannied wall,
I pluck you out of the crannies;
Hold you here, root and all, in my hand,
Little flower—but if I could understand
What you are, root and all, and all in all,
I should know what God and man is."

Though Science—Science with a capital S—is often contrasted with Art—Art with a capital A; though the former is held to be dry and unattractive, while the latter stirs the imagination and arouses "thoughts that breathe and words that burn;" yet the follower of science now and then is rewarded for his toil by an ordered sequence which appeals to the imaginative side of his nature, no less than the rhythmic harmony of poetry, or the measured cadences of music. Indeed, it is not impossible for the poet to express better than, and as truly as in, the pages of the Philosophical Transactions the highest generalizations of science. In this Tennyson stands unrivalled. Take, for example, the stanzas:

"There rolls the deep where grew the tree,
O earth, what changes hast thou seen!
There where the long street roars, hath been
The stillness of the central sea.

The hills are shadows, and they flow
From form to form, and nothing stands;
They melt like mist, the solid lands,
Like clouds they shape themselves and go."

It contains an epitome of the whole of geology. The science is mere elaboration of the ideas contained in Tennyson's beautiful verses.

The difficulty in gaining the appreciation of the "general public" is in presenting the ideas in intelligible language. That the scientific and the romantic are sometimes closely intermingled is indisputable; but the romance is one which appeals to few. In the following pages an

[1] Reprinted from The Contemporary Review, November, 1898, by permission of the Leonard Scott Publication Company.

attempt will be made to show how the thoughts of many men, each striving to "increase natural knowledge," as the formula of admission to the Royal Society runs, have led to a discovery of some interest—that of a hitherto unsuspected constituent of atmospheric air.

The Roman poet Lucretius, a friend and contemporary of Cicero, was the author of a poem entitled "De Rerum Naturâ" ("On the Nature of Things"). In this poem, which treats of almost all things in heaven and earth, he argues that the atoms, the existence of which is obvious because one sees them in a cone of light passing through a dark room, fall rapidly together in their dancing course throughout the spheres, and by their collision engender all known things. Their paths are, however, not directed, but fortuitous; and, therefore, the world is the product of chance.

Passing over many centuries, we find Boyle, in the reign of Charles II, suggesting that the difference between different kinds of matter is to be explained by the nature and the motion of the particles or atoms of which they are composed. The region of speculation was narrowed when Daniel Bernoulli, in 1738, attempted to account for the law, due to Boyle, that the volume of gases varies inversely with the pressure to which they are exposed; and similar attempts were made by Herapath in 1821, and by Joule in 1851. Their ideas were systematized by Clausius in 1857 under the name of the "Kinetic Theory of Gases."

Briefly stated, the theory is this: Granted that in gases the particles—or, as they are now termed, the molecules—of which they consist are widely separated from each other, and that the pressure which the gas exerts on the sides of any vessel in which it may be confined—a pressure which may be realized by pumping away the air outside the vessel, when, if the vessel is constructed of yielding material, such as bladder, it will distend, and ultimately burst—is caused solely by the bombardment of the molecules of gas on the walls. It is at the first blush not very easy to conceive of a steady pressure being due to an enormous number of impacts irregularly delivered. But there are many analogies which help to form the conception. For instance, a musical note, which may strike us as of the utmost smoothness and uniformity, is in reality the result of a succession of blows on the tympanum of the ear, each following the preceding one too rapidly for our ears to distinguish the break in continuity. In a similar manner the pressure of a gas is accounted for. And the temperature, a rise in which also increases the pressure of a gas on the walls of a vessel containing it, is attributed to the increased velocity of the molecules of the gas. Now, for simplicity's sake, considering a blow given by only one molecule, the force of the blow—to use a rough expression which will serve the purpose—will depend not merely on the rate at which that molecule is moving, but also on the weight of that molecule. So that a light molecule with a high rate of motion may deliver as forcible a blow as a heavy molecule with a slower rate of motion. By Clausius's hypothesis, the temperatures of two gases are believed to be equal when the products of their masses into the square of their rates of motion are equal. This is not quite the same thing as saying "when the force of the blows they give is equal," but it may be taken as connected with it.

Supposing, then, that two gases are at the same temperature—that when placed in contact neither gives up heat to the other—then the product above mentioned must be equal for both. For it is obvious that the specifically lighter gas must have the higher velocity; that is, the molecules must be endowed with a higher rate of motion.

What is that rate of motion? Clausius was able to answer that question: A molecule of hydrogen, the lightest gas known, if it moved in a straight line, unimpeded in its motion by collision with any other molecules or with any solid body, would pass through no less than a mile and a quarter in a second. And a molecule of oxygen equally free to move would travel through space with a velocity of rather less than one-third of a mile per second. The relative rates of motion are therefore in inverse proportion to the square roots of the densities of the gases. Thus, as oxygen is sixteen times as heavy as hydrogen, a molecule of hydrogen would move through space in a straight line, were it free to do so, at a rate four times as great as that at which a molecule of oxygen moves.

These rates of motion are calculated for the temperature of melting ice. But as the effect of rise of temperature is to quicken the rate of motion of molecules of gases, so fall of temperature will cause a decreased velocity. The question arises: Is there any possibility of so lowering temperature that the motion of such moving molecules will cease? Judging by the rate at which the pressure of a gas decreases with fall of temperature, there is. That temperature has been called the "absolute zero of temperature:" it lies 273° below the melting point of ice on the centigrade scale, or at −460° on the Fahrenheit scale, the one commonly in use in this country. This temperature has not been reached; it is unlikely that it will ever be reached; but an approach has recently been made to it by liquefying hydrogen gas and allowing it to boil at the atmospheric pressure. The temperature reached in this manner is about −243° C.; and Professor Dewar, who has recently succeeded in liquefying hydrogen in quantity, will no doubt be able to produce a still lower temperature by causing the liquid hydrogen to boil in a vessel connected with an air pump, so that the pressure is reduced. For, just as raising the pressure raises the boiling point of a liquid, as exemplified in the boiler of a steam engine, so lowering the pressure lowers the boiling point.

It is now many years since Dr. Johnstone Stoney applied the kinetic theory of gases, in a series of papers read before the Royal Dublin Society, to the question of the existence of atmospheres on planets and satellites. If a molecule happens to be moving on the surface of a planet at a rate which would carry it away from the planet more rapidly than the planet can draw it back, that molecule will escape into space. It is not theoretically impossible, although practically unrealizable, to construct a gun which would fire a bullet vertically into the air at such a rate that the bullet might never return to the earth. What, then, would occur to it? Well, it would wander on through space as a little planet, performing an ellipse round the sun, as, indeed, many aërolites or "shooting stars" are known to do. It might, indeed, chance to come within the range of attraction of some planet—e. g., Jupiter—massive enough to hold it; or it might actually fall on the surface of a planet; in the former case, it would act like a little satellite, and revolve round that planet, as the numerous stones of which Saturn's rings are composed revolve round Saturn; in the latter case, it would simply become part of that planet, as the falling stars which reach the earth form, after their fall, a portion of the earth.

The molecule of gas, which we have been considering, differs in no particular from a bullet in its wanderings or in its fate. If it chance to come within the sphere of attraction of a planet of sufficient mass to retain it, it will, according to Dr. Stoney, form part of that planet's atmosphere. If not, it will wander on, until it may, by chance, come near enough to the sun to fall a victim to its enormous attractive force, and it will then become part of the sun's atmosphere.

Dr. Stoney has summed up the results of various inquiries of this kind in a memoir entitled Of Atmosphere upon Planets and Satellites.[1]

One important point has been omitted in the sketch given of the kinetic theory. It is this: When it was said that a molecule of oxygen moves at the rate of about one third of a mile per second, it was not implied that all molecules are moving at that rate. Some, urged on by collisions from behind, acquire a much more rapid rate; others, hindered in their motion by collisions with other molecules moving more slowly than themselves, or in an opposite direction, have their rate of motion decreased. A gas must be conceived as composed of an almost infinite number of such molecules, jostling each other in every conceivable way. The rate of one-third of a mile per second, deduced by Clausius as the average rate of motion of a molecule of oxygen, must be understood to mean that if all the rates of motion were to be balanced out, so that the swiftly moving molecules gave up some of their motion to the slowly moving molecules, and vice versa, the molecules would all be moving at the above mentioned rate. But it must be distinctly borne in mind that this imaginary state of things never occurs. There are always many molecules moving faster, many slower, than the average.

I find in my own case that it helps greatly to a clear understanding of such a conception as that of which a short account has been given if a mental picture can be called up which will illustrate the conception,

[1] "Royal Dublin Society," Vol. VI, November, 1897, pp. 305–328.

although even imperfectly. Some such picture may be formed by thinking of the motions of the players in a game of football. At a critical point in the game the players are running, some this way, some that; one has picked up the ball and is running with it, followed by two or three others; while players from the opposite side are slanting toward him, intent upon a collision. The backs are at rest, perhaps; but, on the approach of the ball to the goal, they quicken into activity, and the throng of human molecules is turned and pursues an opposite course. The failure of this analogy to represent what is believed to occur in a gas is that the players' motion is directed and has a purpose; that they do not move in straight lines, but in any curves which may suit their purpose; and that they do not, as two billiard balls do, communicate their rates of motion one to the other by collision. But, making such reservations, some idea may be gained of the encounters of molecules by the encounters in a football field.

In considering averages, it is clear that there must be a practical limit on both sides of the mean. If a man throws dice, he may turn up sixes thrice in succession, or some greater number of times, by chance; but it is clear he will not go on throwing sixes forever, though there is no absolute reason why he should not. Similarly, in thinking of the rates of motion of molecules, there will be a practical limit of rate at which any one molecule will move. It is unlikely that any one molecule will cease to move for any appreciable time; and it is unlikely, too, that any one molecule will develop any exceptionally rapid velocity, say twenty times the mean. Still, such events may conceivably occur; they will, however, be very infrequent.

Those gases which are light, and whose molecules have a high intrinsic average rate of motion, will, in the nature of things, contain some molecules which happen to be moving at a high speed; and necessarily will contain more such than a gas of higher density, the average rate of motion of whose molecules is slower. It may happen that molecules of each kind, of gas with low as well as of gas of high density, may possess such exceptionally high velocity at the confines of our atmosphere, where there are comparatively few gaseous molecules altogether; and it may also happen that these molecules are moving in a direction more or less nearly perpendicular to the surface of the planet, and it may also happen that such molecules suffer no collisions in their vertical path; if these events all happen, the molecules will escape. But as, on the doctrine of chances, there are more molecules of light gas endowed with such exceptionally high velocity than there are of heavy gas, more molecules of the former will escape away from the neighborhood of the planet and enter free space as independent entities than of the latter.

Such a process, prolonged over ages, will ultimately remove from the atmosphere of a planet all gases possessing less than a certain minimum density.

The next question to which Dr. Stoney addresses himself is: What rate of motion must a molecule have in order that it may escape from the attraction of the earth? The least velocity which will enable such a molecule to escape is about 7 miles per second. And it is assumed, from observations taken at high altitudes, that the temperature of the upper regions of the atmosphere is about −66° C., or about −87° F.

This velocity of 7 miles a second is, however, considerably greater than the average velocity of a molecule of hydrogen, which, at 32° F., it will be remembered, is only about a mile and a quarter. But it is not greater than the velocity of some of the molecules; and these will therefore escape. In fact, Dr. Stoney concludes that in every gas a considerable proportion of the molecules have a velocity at least ten times as great as the mean.

Now on this earth the important constituents of the atmosphere are nitrogen, oxygen, argon, carbon dioxide, water vapor, and ammonia; and their densities are as follows, that of hydrogen being taken as unity:

Nitrogen	14
Oxygen	16
Argon	20
Carbon dioxide	22
Water gas	9
Ammonia	8.5

We are here chiefly concerned with the gases of the earth's atmosphere; but it may be of interest to cast a glance at other conclusions which follow from Dr. Stoney's speculations.

The moon, the mass of which is much less than that of the earth, would retain a gas of density 40, or thereabouts; but all less dense gases would escape rapidly. From the planet Mercury water vapor would at once escape, and it is probable that both nitrogen and oxygen would escape more slowly. Argon and carbon dioxide might, however, be permanent constituents of the atmosphere of Mercury. Venus, on the other hand, retains water vapor; but lighter gases would escape. It must be remembered that if the water were to escape from a planet in the state of vapor, its place would be at once supplied by evaporation of planetary seas, if there were any, and that, in the long run, all the water would, in the state of gas or water, leave the planet.

Indeed, Dr. Stoney thinks it not unlikely that we are slowly losing our stock of water. This, however, need excite no alarm, and our water will probably outlast our coal many millions of years. For so few of the molecules of water comply with the required standard of velocity that the rate of loss is almost infinitesimally small.

Similarly Dr. Stoney conjectures that water can not remain on Mars; that all known gases would be imprisoned by Jupiter; and that Saturn, Uranus, and Neptune may probably be able to retain all gases heavier than hydrogen. As for the sun, its mass is so enormous relatively to that of the planets that, even at the exceedingly high temperature which its atmosphere possesses, it is impossible for any known gas to remove itself from the neighborhood of the luminary.

We must now take leave of Dr. Stoney's fascinating hypotheses for a time, and consider the recent discoveries of gaseous constituents of our atmosphere.

After the discovery of argon as a constituent of air in 1894, one of the discoverers, acting on advice given him by Professor Miers, was so fortunate as to isolate helium, a gas contained in certain rare minerals, the best known of which bears the name of clèveite. Helium had previously been detected in the chromosphere, the colored atmosphere of the sun, by M. Janssen, the well-known French astronomer; and its name was suggested by Messrs. Frankland and Lockyer, in 1868, to characterize the brilliant yellow line by which its presence in the sun is revealed. Neither of these elements has been combined with others, although it is possible that each exists in combination with one or more of the elements contained in the minerals from which helium can be obtained by heating, for it has been found that small quantities of argon, along with considerable quantities of helium, are evolved from such minerals. Again, both of these elements possess one curious property, which they share with gaseous mercury alone, so far as is known, among all elements. That is technically called the ratio between their specific heats at constant pressure and at constant volume. It would be difficult here to set forth the reasoning by which it is deduced that inasmuch as the ratio for these gases is $1\frac{2}{3}$ to 1 between specific heat at constant pressure and at constant volume, the molecules of these elements, unlike those of oxygen and hydrogen and the other commoner gases, but like those of mercury gas, consist not of agglomerations of two or more atoms, but of single atoms. These characteristics at once establish a connection between the two elements helium and argon, and differentiate them in kind from all other gaseous elements.

Now, taking the density of hydrogen as unity, that of helium is very nearly 2, and that of argon 20. And one of the conclusions which follows from the Kinetic theory of gases is that equal volumes of gases contain equal numbers of molecules. Thus the fact that helium is twice as heavy as hydrogen carries with it the conclusion that a molecule of helium is twice as heavy as a molecule of hydrogen, whatever the absolute weight of the latter may be.

Now, it can be demonstrated that there is a strong probability in favor of the assumption that a molecule of hydogen consists of two atoms, inseparable from each other unless by combination with some other element. And if a molecule of helium consisting of one atom is twice as heavy as a molecule of hydrogen consisting of two, then it follows that an atom of helium is four times as heavy as an atom of hydrogen; in other words, the atomic weight of helium is 4, that of hydrogen being taken as 1. Similar reasoning proves the atomic weight of argon to be 40, from the known fact that it is twenty times as heavy as hydrogen. Moreover it is noteworthy that the difference between these numbers 40 and 4 is 36.

Mr. John Newlands, whose recent death is deplored by the scientific world, as long ago as 1863 brought forward what he termed a "law of octaves." It consisted in arranging the numbers which represent the atomic weights of the elements in seven rows, beginning again with the eighth element, so that its atomic weight occupies a position in the table below that of the first, the ninth below the second, the fifteenth again below the first, and so on. The reproduction of three of such rows will make the meaning clear.

Li 7	Be 9·2	B 11	C 12	N 14	O 16	F 19
Na 23	Mg 24·3	Al 27	Si 28	P 31	S 32	Cl 35·5
K 39	Ca 40	Sc 44	Ti 46	V 52	Cr 52·5	Mn 55

&c. &c.

The elements appear in this table in groups, of which the individual members closely resemble each other, often in appearance, and always in the nature of the compounds they form with other elements. Thus, to take the first column, the three elements, lithium, sodium, and potassium, together with others not here produced, but which occur later on in the table, rubidium and cæsium, are all white waxy metallic solids, easily cut with a knife, tarnishing rapidly in contact with ordinary moist air, and forming compounds which themselves present the greatest resemblance to one another. Now, in Mr. Newlands's view, the fact that the eighth element resembles the first suggested an analogy with the musical scale, where the tones can be similarly classified, each eighth note of the major scale reproducing, as it were, the fundamental note. In the ordinary notation, the name C refers to many notes, separated from each other by octaves. The analogy may be regarded as fanciful, and in the light of more modern work the word "octave" is here inapplicable; and this perhaps overstrained analogy did much to discredit Mr. Newlands's views in the eyes of the leading chemists of the day. It was not until 1868, when the late Prof. Lothar Meyer, and Professor Mendeléef independently arrived at a similar arrangement, that the attention of chemists was recalled to the subject, and the justice of Mr. Newlands's ideas was acknowledged. The somewhat tardy award of a medal by the Royal Society placed in its true position the work of Mr. Newlands, and was regarded as an act of justice by his friends. It is deeply to be regretted that his recent death has removed from our midst a man so kindly and so alive to every advance in science.

The elements helium and argon, if they be really elements and not compounds (and there is no reason to doubt their elementary nature), should find places in this table, now known as the "Periodic Arrangement of the Elements." And confining our attention to only a few of the vertical columns, their position should be for helium before lithium, and for argon before potassium, thus:

Hydrogen... 1	Helium.. 4	Lithium.... 7
Fluorine.... 19	?	Sodium 23
Chlorine 35.5	Argon ... 40	Potassium.. 39
Manganese.. 55	Iron..... 56 Cobalt .. 58 Nickel .. 59	Copper 63.5
Bromine 80	?	Rubidium .. 85

Now, we find the difference between the atomic weights of hydrogen and chlorine to be 34.5; and between lithium and potassium to be 32; also between argon and helium to be 36. These numbers are roughly of the same order of magnitude. It is, therefore, not unreasonable to suspect the existence of an undiscovered element with atomic weight between 19 and 23, as well as of others occupying the other unfilled positions in the argon group.

It is no easy matter to hunt the earth through for an unknown element. The question is, where to look. And some clew is necessary to guide the inquiry. At first it was thought that minerals similar to those from which helium had been obtained might possibly yield the new element; and experiments were made, for months at a time, to test the gases obtainable from almost every known mineral, but in vain, so far as a new element was concerned. They resulted in the discovery of many new sources of helium, but the spectrum of the gas in each case exhibited no unknown lines. A new method of attack was then organized. It might be that the so-called helium was really a mixture of elements, and not a pure element. Now, an effective method of separating from each other two gases of different molecular weights, and hence of different densities, is the process of diffusion. From observations of the late Professor Graham, of University College, London, subsequently master of the mint, it appears that lighter gases, with rapidly moving molecules, will pass through a porous diaphragm, such as the material of a clay pipe, more rapidly than a heavier gas, with its more slowly moving molecules. An attempt was therefore made to ascertain whether any heavier gas could be thus separated from the helium obtained from minerals. The experiments involved an enormous amount of labor, but in the end no gas other than a trace of argon could be detected. It appeared, therefore, vain to attempt to discover a new gas in minerals; and the justice of Dr. Stoney's hypothesis was next tested. It was, of course, not out of the question that the sought-for gas might exhibit some powers of combination, and that it might have been absorbed, along with the nitrogen of the air, by the magnesium over which the gas had been sent at a red heat, in order to absorb and remove the nitrogen. The compound of magnesium with nitrogen is very readily decomposed by water; the products are ammonia and hydroxide of magnesium. A large quantity of this magnesium nitride was accordingly treated with water, and the resulting ammonia absorbed by means of weak sulphuric acid. There was merely a trace of gas which refused to be absorbed, and on examination it turned out to be the familar hydrogen, which was formed by the action of the water on some metallic magnesium which had escaped combination with nitrogen. This experiment was interesting, inasmuch as it proved that magnesium refuses to combine with even the smallest trace of argon. The ammonia resulting from this treatment, it is true, might have conceivably contained a compound of the new gas, but a similar sample had previously been decomposed, so as to obtain from it its nitrogen, and that sample of nitrogen had been found by Lord Rayleigh to possess the same density as a sample of nitrogen of which the source could not be traced to the atmosphere. Lastly, it was conceivable that the hydroxide of magnesium might have contained some compound of the new element. It was therefore treated with water, and the soluble portion separated from the insoluble. The soluble portion, on examination, proved to contain nothing but the carbonate of magnesium. The insoluble portion was not further dealt with, but was kept in reserve.

The argon of the atmosphere was next examined. A large quantity having been prepared, it was purified, and by passing it into a vessel immersed in liquid air, made to boil at even lower temperature than usual by pumping away the air-gases as they boiled off, the argon, too, was completely changed into liquid. Liquid argon is clear and colorless, whereas liquid air has a faint blue tint, owing to the blue color of the oxygen it contains. The argon was next made to boil, by allowing the temperature of the liquid air to rise a few degrees, and the first portions of argon-gas were collected separately, the remainder going back into the gas-holder in which it had originally been stored. The gas thus obtained was lighter than argon and more difficult to liquefy; this was shown by the necessity of compressing it into the bulb in which liquefaction took place. The most volatile portions of this liquid were next collected separately, and the gas proved to be still less dense than the former sample. It was not possible to liquefy more than a small fraction of this last specimen of gas, to however low a point the temperature of the boiling air was reduced; and after another repetition of the same process the gas appeared to be as light as the process could make it. Its density was 9.75 times that of hydrogen, and making allowance for a small quantity of argon, which it must necessarily have contained, this number becomes reduced to 9.6.[1] The weight of a molecule, compared with the weight of an atom of hydrogen, as previously explained, must therefore be 19.2; and 19.2 lies between the atomic weights of fluorine, 19, and of sodium, 23, fall-

[1] This gas has since been found to contain a trace of helium, the presence of which would lower the above density. The actual density will, therefore, be somewhat higher than 9.6, but it will probably not exceed 10. It has not yet been determined.

ing therefore into the predicted place in the Periodic Table. The specific heat ratio of this new gas, to which the name "neon" or "the new one" has been given, is, as in the case of helium and argon, $1\frac{2}{3}$; like them, too, it resists combination with other elements and possesses a brilliant and characteristic spectrum.

This account of the fulfillment of a prediction has, I am afraid, been somewhat elaborate for the general reader; but it is interesting as a case of discovery, where many lines of evidence, founded on the work of many different observers, have led to the foreseen conclusion. It possesses, to my mind at least, some of the qualities of a scientific poem: An orderly arrangement of ideas, drawn from many different sources, each throwing light on the other, and all tending toward a final event. It is true that the subject is not one to which poetical diction can be applied with advantage; the details are too complicated, too unfamiliar, and to be expressed only in language which has not received the impress of poetical tradition; but to enlarge on this would open a wide field of discussion, in which æsthetics, a subject not as yet reduced to accurate formulation, and perhaps hardly susceptible of treatment by scientific methods, would form the chief theme.

In epic poems the "argument" usually precedes the matter. Here it may be convenient to reverse the order, and to sum up the preceding pages by the argument. We have seen, then, that the discovery by Lord Rayleigh of a discrepancy in the density of atmospheric nitrogen has resulted in the discovery of a new constituent of air, argon; its discovery has led to that of a constituent of the solar atmosphere, helium; speculations on the ultimate nature and motion of the particles of which it is believed that gases consist has provoked the consideration of the conditions necessary in order that planets and satellites may retain an atmosphere, and of the nature of that atmosphere; the necessary existence of an undiscovered element was foreseen, owing to the usual regularity in the distribution of the atomic weights of elements not being attained in the case of helium and argon; and the source of neon was therefore indicated. This source, atmospheric air, was investigated, and the missing element was discovered. A new fact has been added to science, and one not disconnected from others, but one resulting from the convergence of many speculations, observations, and theories, brought to bear on one another.

THE REVIVAL OF INORGANIC CHEMISTRY.[1]

By H. N. STOKES.

Nothing can be more instructive to the student interested in the results of intellectual cross fertilization than the effect of the recent fecundation of chemistry by physics. Through the application of physical methods and ideas to chemistry, the latter has given birth to a new branch of study, physical chemistry, which promises to produce as radical a change in our conceptions of molecular phenomena as did the overthrow of the phlogiston theory or the introduction of the conception of valency at a later period.

The attempt of Berthollet to introduce dynamical conceptions into chemistry, at the beginning of the century, fell on thorny ground, and from that day until very recent years the growth of chemistry, great as it has been, has been most remarkably one-sided. The Periodic Law has been discovered, many new elements have been found, new compounds without number have been prepared, the rules governing their formations and transformations have been ascertained, and even their microscopic anatomy has been studied to such an extent that for countless of them we have established formulas which express, schematically, the relative arrangement of the atoms in the molecule. In stereochemistry we have even gone so far as to be able to indicate, in a rough way, the actual relations of the atoms in space; yet, with all this, a most important part of the problem has been almost neglected. To use a biological expression, chemistry has been enormously developed on the morphological, and but little on the physiological side. Chemists have concerned themselves greatly with the products of chemical reactions, and but little with the nature of the reactions themselves. The molecule has been treated as a dead, rigid body is treated by the anatomist, but its study as a living, moving mass, filled with energy and capable of reacting by virtue of this energy, has been largely left to the future. Even as late as 1882 the German physiologist Emil du Bois-Reymond used the words which have since been in the mouth of every physical chemist: "In contradistinction to modern chemistry, we may call physical chemistry the *chemistry of the future.*"

[1]Annual address of the president of the Chemical Society of Washington, delivered March 30, 1899. Reprinted from Science, N. S., Vol. IX, No. 226, pp. 601–615, April 28, 1899.

Since 1882, thanks to the labors and inspiring influence of Ostwald, van't Hoff, Arrhenius, Nernst, and others, physical chemistry is no longer the chemistry of the future merely, but of the present, and apart from the quickening influence which it is exerting in nearly all branches of chemistry proper, both pure and applied, we are beginning to perceive that we are entering a period in which chemistry will be of greater service to the allied sciences. Geological chemistry is showing signs of reviving under the stimulus of physico chemical conceptions, and we are finding, too, that as physiological chemistry is not merely the chemistry of sugar, or urea, or albumin, but preeminently a science of moving and changing molecules, it can only progress by the aid of a knowledge of the laws of chemical energy.

The achievements of physical chemistry form, perhaps, the most interesting phase of the recent history of our science, but its followers have spoken for themselves so often of late years, and have presented the subject so much better than I could do it, that I feel compelled to consider a perhaps humbler, but yet not unimportant, field of research, which, in a sense, may also be called a part of the chemistry of the future, the field of Inorganic Chemistry. The relations of physical and inorganic chemistry have recently been discussed by van't Hoff in his admirable address delivered last summer before the Society of German Scientists and Physicians, and I shall, therefore, limit myself to the consideration of a few points of a more strictly chemical nature, touching the relations of physical and inorganic chemistry only incidentally.

The aim of physical chemistry will have been accomplished when it has established a mathematical equation which, by proper substitution, will enable us to predict the nature of every possible chemical system or reaction, and the properties, physical and chemical, of every possible element or compound. Until he has reached this chemical millennium, unless he will risk falling into the pit which has received so many philosophers in the past, the chemist must continue to advance by the route by which our understanding of every other branch of physical science has been reached. Notwithstanding all that physical chemistry can do with this material at present in hand, the experimenter must long continue to take the short cut to knowledge and find out what his elements and compounds will do by first actually getting them in hand, by precipitation, filtration, distillation, crystallization, and the like. It may be questioned whether our present knowledge of facts would ever suffice to enable us to predict, for example, a single atomic weight with accuracy, or to explain that wonderful relation between properties and atomic weights known as the Periodic Law. A few enthusiastic physical chemists have spoken slightingly of the compound maker as a kind of inferior being, apparently forgetting that it is just this kind of pioneer work which has supplied the material for their labors, that the first requisite for successful generalization is the possession of a large number of pure substances, of accurately known composition and properties, many of which can only be obtained by work which is so elaborate and difficult, and which requires such concentration of effort, that he who follows it can well be excused if he does not always look on the product of his labor as merely means to another end. It is tolerably clear that, for a long time to come, experimentizing must keep equal pace with mathematizing, and if the former have been pushed so far in one direction as to appear to afford no prospect of continued progress we must not abandon it altogether, but consider whether it may not be still profitably pursued along other lines. Let us consider whether we must all turn mathematical chemists, or whether there is not much left to be done by those trained in the older school, working along old-fashioned lines and by old-fashioned methods.

Descriptive chemistry, as it exists to-day, is a science which has grown and is still growing enormously in a single direction, that of organic chemistry, the chemistry of the compounds of carbon. We are at present acquainted with about seventy-five chemical elements, which are found in the most varied proportions in those parts of the earth which are accessible to our observation, namely, the crust, the sea, and the air. The accompanying table, calculated by Clarke, shows the relative abundance of the elements in a sphere comprising the crust for a depth of 10 miles, the ocean, and the atmosphere:

Oxygen	49.98
Silicon	25.30
Aluminium	7.26
Iron	5.08
Calcium	3.51
Magnesium	2.50
Sodium	2.28
Potassium	2.23
Hydrogen	.94
Titanium	.30
Carbon	.21
Chlorine, Bromine	.51
Phosphorus	.09
Manganese	.07
Sulphur	.04
Barium	.03
Nitrogen	.02
Chromium	.01

The nineteen elements here given make up nearly the whole mass; the remaining fifty-five or thereabouts, taken together, and making all possible allowance for error, do not amount to more than 1 per cent. Observe that the element carbon amounts to but one-fifth of one per cent. To be sure, this is no argument that the chemistry of carbon is relatively unimportant; on the contrary, there is no necessary connection between the abundance of an element and its ability to carry us further toward a knowledge of chemical laws. Nevertheless, to an intelligence not having its seat in a body largely made up of carbon compounds, it might appear somewhat surprising that chemists should have attempted to base a science on the investigation of an element which exists in such relatively insignificant amounts, the compounds of which, with but few exceptions, are incapable of formation at the freezing point of water, or of existence at the lowest red heat, and should have chosen to devote nearly all of their energy to its study.

Apart from the special subject of coal, petroleum, and asphalt, carbon is of practical importance to the geologist only in the form of carbon dioxide and the carbonates, while of the chemical properties of silicon, which constitutes 27 per cent of the earth's crust, and of the silicates, which make up nearly all of it, we know vastly less than of the derivatives of the single carbon compound, benzene. A study of the chemical changes taking place in the sun, and of most of those occurring in the interior of the earth, might almost leave carbon out of account; it would certainly have no more importance than titanium, an element of which few but chemists have ever heard, but which is more abundant and as widely distributed.

Carbon, as an essential constituent of living beings, constantly forces itself on our attention, yet this is not to be considered as by any means the chief cause of the predominance of organic chemistry. Comparatively few of the best-studied organic compounds have more than the remotest connection with the phenomena of life. Phosphorus and sulphur, to say nothing of oxygen, hydrogen, and nitrogen, are quite as important in this respect as carbon, yet how relatively little do we know of phosphorus and sulphur in their chemical relations, or even of nitrogen. The extraordinary development of carbon chemistry is due mainly to reasons of a chemical nature, which, by rendering its compounds easier to study, have made progress in this direction a line of least resistance. This has not been without its advantages, for we have been led to discern laws which could not have been perceived so soon had the working forces been more evenly distributed, but it has also had the unfortunate result that the theories of molecular structure, derived wholly from the study of carbon compounds, have been applied to all classes of inorganic compounds too hastily and without sufficient research. The inorganic chemist has done little but make new compounds, and ascribe to them structural formulas seldom based on the results of experiment, but rather on the possibility of drawing schemes on paper, in which the various valences or bonds were mutually satisfied (how, did not matter much), while those substances which were inconsiderate enough to refuse to submit to this operation without violating every probable or possible assumption have been labeled "molecular compounds" and under this name submitted to a forced neglect, which soon resulted in their being forgotten. We shall presently see that an increasing respect for these so-called molecular compounds is one of the features of the revival of inorganic chemistry.

In the earlier days of chemistry no sharp line was drawn between inorganic and organic substances. It is generally thought that we owe this distinction to Nicholas Lémery, who, in 1675, classified substances according to their origin, as mineral, vegetable, and animal, a distinction which has survived until the present day in popular speech. Lavoisier, recognizing in substances of vegetable and animal origin the elements carbon, hydrogen, nitrogen, and oxygen, and led by his researches to attribute a peculiar importance to oxygen, regarded inorganic bases and acids as oxides of simple radicals, and organic bodies as oxides of compound radicals composed of carbon, hydrogen, and sometimes nitrogen, but did not otherwise distinguish them. Even in 1811 it was undetermined whether carbon compounds obey the laws of constant and multiple proportions, and it was two or three years more before Berzelius, having sufficiently improved the methods of organic analysis, definitely proved that they do, in fact, conform to these laws, but are of greater complexity than the comparatively simple inorganic compounds then known. In his electro-chemical theory, the theory of dualism, developed between 1812 and 1818, Berzelius regarded the simple inorganic bodies, such as the bases and acids, as binary compounds of positive with negative atoms, held together by electrical attraction; the more complex bodies, as the salts, being binary compounds of a higher order; the organic compounds, on the contrary, being regarded as ternary or quaternary. Later he extended the dualistic conception to these also, adopting the idea of Lavoisier that they are binary compounds of oxygen with compound radicals, composed of carbon, hydrogen, and sometimes nitrogen, a view which he developed further and never wholly abandoned. In 1817 we find Leopold Gmelin maintaining that organic compounds are the products of a vital force and can not be produced artificially. This view was entertained by Berzelius even as late as 1827, or later. Berzelius attributed the formation of organic compounds, with their relatively weak positive and negative characters, to peculiar electrical conditions existing in the organism. We can not reproduce these conditions in the laboratory, and, therefore, can not produce organic compounds artificially. Those transformations which we are able to effect are always from the more complex to the simpler. We can isolate the intermediate stages in the breaking down of organic matter into carbon dioxide, water and ammonia—that is, we can follow the change of matter from the organic to the inorganic, step by step—but we can not reverse the process and build up, nor can we hope to do so in the future. This opinion of Berzelius marks the widest gulf between organic and inorganic chemistry, a gulf too wide for human power to bridge. How dangerous it is to set limits to the power of science! But one year later, in 1828, Wöhler announced his discovery that urea, a body of animal origin, could be produced from ammonium cyanate, a substance which, in its turn, can be built up from its constituent elements, carbon, hydrogen, oxygen, and nitrogen. This was the first of a series of innumerable syntheses which have fully disposed of the idea that any fundamental distinction exists between inorganic and organic compounds. Although we have not yet made albumin in the laboratory, we all expect that it will be done, and nearly every chemist now believes that even the properties of living protoplasm are due, not to any peculiar vital force inherent in the protoplasm itself, but to the special properties of the carbon, hydrogen, oxygen, nitrogen, phosphorus, and other elements of which it is composed. My subject does not permit me to consider in detail how the idea of organic chemistry, as the chemistry of compound radicals, was evolved; how the radical theory was replaced by the conception of the molecule as a unit; how, in 1853, the theory of valency began to develop, and how this, with the type theory, the theory of the linkage of atoms, and the constant tetravalency of carbon, led, in the early sixties, to our present conceptions of the structure of organic molecules. With the advent of the fully developed structural formula, the brilliant progress of organic chemistry toward fuller theoretical development came to an end with remarkable suddenness. Kekulé's ingenious and fruitful theory of the benzene ring, suggested in 1865, was an application to a particular class of compounds of principles already established, but involved no fundamentally new conceptions. Organic chemistry entered upon what has aptly been termed a period of "formula worship." The establishment of the constitutional formula became the highest aim of the devotees of this cult, against which but few chemists, for example Kolbe and Mendelejeff, have had the courage to protest. In pursuing this aim the organic chemists have unquestionably accumulated an enormous mass of valuable information and detail; have discovered new methods of synthesis, new laws of more or less special application, and new compounds of practical value; but, with all their labors, the ordinary structural formula of to-day means no more than it did in 1865. In stereo-chemistry, however, the development of the structural formula in space of three dimensions, organic chemistry has shown real progress, especially since 1887, when LeBel and van't Hoff's theory of the asymmetric carbon atom, which was proposed in 1874, but which slumbered almost forgotten, was revived by Wislicenus. At present the most important developments of structural chemistry, both organic and inorganic, unquestionably have the question of space relation as their basis.

The development of inorganic chemistry presents some marked distinctions from that of organic chemistry. Up to the year 1820 nearly all the important discoveries and generalizations came from the inorganic side. Richter's discovery of the law of equivalents; the researches of Scheele, Cavendish, Priestley; the development of the theory of oxidation by Lavoisier; the atomic hypothesis of Dalton and his laws of constant and multiple proportions, and the placing of them on a firm foundation by the remarkable labors of Berzelius; Gay Lussac's law of the simple relation of the volumes of reacting gases; Dulong and Petit's law, and the law of isomorphism, all fall within this period and antedate the beginning of the rapid development of carbon chemistry. The same is true of the discovery of the alkali metals, the recognition of the elementary nature of chlorine, and of the establishment of the existence of hydrogen acids, and many other important facts. In these the study of carbon played a relatively insignificant part. The electro-chemical theory of Berzelius, too, which was of such great importance as a working hypothesis, was of inorganic origin. By 1830 the predominance of organic chemistry was already pronounced, and with the increased attention given to this new field the interest in inorganic chemistry lagged behind. All, or nearly all, the developments of theoretical importance began to come from the organic side. The history of chemistry from 1830 to 1865 is practically the history of organic chemistry. I do not mean that research was confined merely to carbon compounds. The influence of Berzelius continued to be felt, and men like Heinrich Rose, Wöhler, Bunsen and many others made valuable contributions to inorganic chemistry, as well as several like Dumas, Liebig, and others, whose reputation rests chiefly on their organic work. The great inorganic chemists were mostly men of an analytical rather than synthetical turn of mind. The growth of mineralogy led to the discovery of new elements, and the analytical requirements to which it, as well as practical chemistry, gave rise conduced largely to the study of inorganic compounds. The conception of valency, while due mainly to organic chemistry, owes not a little to inorganic chemistry, though it did but little to further it. Numerous atomic weight determinations of greater or less accuracy were made, sometimes with a purely analytic purpose, sometimes with the object of testing the validity of Prout's hypothesis, but these exercised but little influence on the theoretical growth of inorganic chemistry, which remained for the most part a mass of unconnected facts.

In considering the causes to which is due the preeminent attention given to organic chemistry since 1830, the point most to be emphasized is that at no time since that date has there been lacking a well-defined working hypothesis of the nature of organic compounds. Not only did these substances prove eminently susceptible of classification into types, but, for reasons to be stated later, the transformations discovered were so numerous, and the possibilities of producing synthetically old or new compounds, and of working out new theories, were so attractive that most of the best chemical minds between 1830 and 1865, or even later, were drawn into organic chemistry. Another important factor is that of inertia. Most students of nature do not willingly enter upon entirely new fields of research. The pupils of the great masters of organic chemistry, Liebig, Dumas, Hofmann, Wurtz, Kolbe, Kekulé, and others, found enough to do in following in the footsteps of their teachers, and were little inclined to seek new pastures. The requirements of candidates for the doctorate, whereby the experimental material for the dissertation had to be accumulated in a comparatively short time, led to the assignment of topics with which the instructor was familiar, and which were fairly sure of giving positive results within a year or two, and, as we all know, no branch of chemistry yields results so readily as the study of carbon compounds, with its highly developed synthetical methods. As the Chemiker-Zeitung has recently pointed out, even at the present day the full professorships in German universities are almost invariably held by organic chemists, while inorganic chemistry is left to subordinates. The weight of authority and influence being on the side of organic chemistry, the student who looks forward to a university career sees that his chances of promotion are better if he follow the organic rather than the inorganic direction. I need hardly add that the more mercenary hope of obtaining a new dyestuff or a new remedy, or of replacing nature in making an alkaloid, has also been a powerful incentive to many.

Let us now consider some of the reasons which have their root in the chemical peculiarities of carbon, and which render its compounds, at least those which are not too complex, comparatively easy to study. These conditions are not peculiar to carbon, but no other element, as far as is known, presents as many of them at the same time.

1. Carbon compounds being very generally soluble in neutral solvents, frequently crystalline, and often volatile without decomposition at comparatively low temperatures, are peculiarly adapted to separation in a state of purity by fractional crystallization or distillation, and for the same reason it is usually possible to determine their true molecular weights. The very general possession of melting or boiling points lying within easily observable ranges of temperature greatly facilitates identification.

2. The power of carbon of uniting, atom to atom, to form chains, the form and size of which can be easily regulated by known synthetic methods, and the stability of which is sufficient to allow of manipulation under easily attainable conditions, is a marked peculiarity of this element. This, with the power of forming stable compounds with hydrogen, is the basis of the definition of organic chemistry as "the chemistry of the hydrocarbons and their derivatives." With regard to self-linking power, the other elements are in marked contrast. We know with certainty no compounds in which two atoms of boron are linked, not more than four nitrogen atoms have been arranged tandem, while of silicon, the nearest relative of carbon, we know at best a half dozen well-defined compounds with two atoms of this element in series, and but one with three; analogues of the hydrocarbons are unknown, with the exception of silico methane, and the instability of this is sufficient proof that a series of silicon paraffins would be most difficult to prepare, and the same would apply to all classes of silicon compounds in which self-linking is a prerequisite. It does not appear probable that

we shall ever have a very extensive chemistry of the "hydrosilicons and their derivatives." Among the compounds of other elements self-linkage occurs in but few cases and is limited in extent.

3. It is a highly important property of carbon compounds that their molecules tend to preserve their individuality; they generally do not, though there are exceptions, spontaneously avail themselves of opportunities for condensation, whether by polymerization or by union of two or more molecules with separation of water or ammonia. The so-called double and triple union between carbon atoms only exceptionally leads to spontaneous polymerization, while with silicon this latter is apparently the rule. The important carbonyl group, C = O, the characteristic group of organic acids, aldehydes, and ketones, shows but little tendency to polymerize, while organic hydroxyl compounds are usually stable and do not spontaneously give rise to ethers or acid anhydrides. The silicon analogue of carbonyl, Si = O, on the contrary, appears to polymerize with great ease. The ethers of carbonic acid are well known, but the metasilicic ethers, those of the type $SiO(OR)_2$, appear to exist only as polymers. The silicic acids, too, show a marked tendency to condense by dehydration and pass spontaneously into complex bodies. It is easy to see what would have been the result if carbon behaved like silicon. Instead of the innumerable sharply defined organic acids, aldehydes, ketones, and alcohols, each produced by a definite synthetic process, each reaction would give rise to an almost inextricable mixture of condensation products, carbon dioxide would be a solid like silica, and organic chemistry would be scarcely further advanced than is the chemistry of silicon. This tendency of carbon compounds to simplicity in reaction, each molecule acting as if it were alone present, has been, therefore, an important factor in facilitating the growth of organic chemistry.

4. Another feature of carbon which plays an important part is the ease with which intermediate or transition products can be formed. It is much easier to limit reactions in the case of carbon compounds than in others. Compare, for example, the action of chlorine on CH_4 and SiH_4.

5. The tendency to dissociation, both hydrolytic and electrolytic, is in general less marked among carbon compounds, whence it is easier to control the course of a reaction and to exclude changes of a spontaneous nature. Finally, the carbon compounds show but little tendency to the formation of so-called molecular addition products, of which the metal-ammonias, the double salts and the compounds with water of crystallization are examples, the rational interpretation of which is difficult.

A full consideration of the peculiarities of carbon which have facilitated the synthesis of such vast numbers of organic compounds would be beyond the scope of this address. The above are the most important, and their relative absence in the majority of elements explains largely the backward state of our knowledge of them. Our inability to determine the true molecular weight of insoluble and nonvolatile substances; the difficulty of limiting reactions so as to obtain intermediate products; of preventing condensations; of separating mixtures and identifying their constituents by such simple methods as melting and boiling-point determinations; of building up step by step; of dissecting atom by atom; of explaining molecular compounds—these are hindrances which can only be overcome by greater perfection of our experimental methods, and which often render the study of the constitution of inorganic bodies a problem of great difficulty, even in the case of many of the simplest.

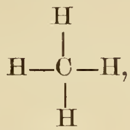
At the very time that the organic structural formula was beginning to turn the attention of organic chemists away from a further development of theory to a greater elaboration of details the Englishman Newlands was publishing papers which contained the germ of the Periodic Law. In 1865 Kekulé announced his theory of the benzene ring; in 1864 Newlands showed that if the elements be arranged in the order of their atomic weights "the eighth element, starting from a given one, is a kind of repetition of the first, like the eighth note of an octave in music." The discovery of Newlands of a fact which later developed into the Periodic Law does not, however, mark the beginning of a new direction in chemical thought. It marks rather that point in a long series of speculations at which chemists were beginning to grasp an idea after which they had been groping blindly for many years, the conception that the elements are not wholly unrelated bodies, but that there is some definite law connecting their properties with their atomic weights. Beginning in 1815, with the claim of Prout that the atomic weights of the elements are multiples of that of hydrogen, which led him to suggest that hydrogen is the primitive element from which the others are built up, we find numerous speculations, some devoted merely to finding arithmetical relations among the atomic weights, such as the law of triads, others attempting to show how the elements could be built up from one or more primitive constituents. Most of these did not lead to any marked advance of chemical theory, but Prout's hypothesis found very able defenders and greatly encouraged accurate atomic-weight determinations. The labors of Dumas, Marignac, and especially of Stas, in this field, are directly due to the desire to test the validity of Prout's suggestion. Up to 1860 not only were the atomic weights uncertain to within a few decimals, but, for other reasons, even the relative position of the elements in an ascending series was often uncertain; our present empirical formulas had not been fully established; it was uncertain, for instance, whether water was HO with $O=8$ or H_2O with $O=16$, or whether silica was SiO_2 with $Si=28$ or SiO_3 with $Si=21$. So when Gladstone, in 1853, arranged the elements in the order of ascending atomic weights he failed to perceive any noteworthy relation. Nine years later the French engineer and geologist de Chancourtois, using the newer and now adopted atomic weights, arranged the elements in a spiral or helical form around a cylinder, in ascending order, and was led to the conclusion that the "properties of bodies are properties of the numbers," a vague statement of the now familiar phrase that the properties of the elements are functions of their atomic weights. As already mentioned, he was followed closely by Newlands, whose work, however, met with but slight recognition. Time is wanting to show how, in the period 1864–1869 the Periodic Law was developed by the labors of Newlands, and more especially of Lothar Meyer and Mendelejeff, working independently. It affords an interesting example of how a great idea is developed about the same time in the minds of several men working independently and unknown to each other. In 1871 Mendelejeff published a table which shows the Periodic Law essentially as we find it to-day, the only changes consisting in the addition of a few newly discovered elements and in placing a few of the older elements in their proper positions, as a result of more accurate atomic weight determinations.

The period 1863–1870 was, therefore, of the greatest importance for inorganic chemistry, as it saw the development of the idea that the properties of the elements are periodic functions of their atomic weights. The time which has since elapsed has been even more fruitful than any previous period in speculations, having for their object the finding of mathematical relations between the atomic weights and in theories of the evolution of matter from one or two primal constituents. Many modifications of the periodic scheme have been devised, but they present but few or no advantages over the simple arrangement of Mendelejeff and Lothar Meyer. The great fact still remains, unmodified and unimproved, that if the elements be arranged in the order of increasing atomic weights there is a recurrence of the properties of elements lower in the scale—in short, that these properties are periodic functions of the atomic weights.

The discovery of the new group of inert gases, helium, neon, argon, and xenon, with perhaps krypton and metargon, has not modified our idea of the Periodic Law essentially. They appear to fit well into the system, and it is now only remarkable that their existence was not surmised by Mendelejeff, who so successfully predicted several then unknown elements. Although the periodic system is even to-day the object of attack by a few chemists, who appear to be blinded by its unquestioned defects to the obvious truths which it expresses, it may be safely said that the great central fact of the periodicity in the properties of the elements is just as firmly established as the law of gravitation, and that, whatever modifications may have to be made in the scheme as a whole, this central fact will never be done away with. The atomic theory may be supplanted by something better, but its successor will equally have to take account of the stoichiometrical relations of the elements, which are based not on theory, but on observation pure and simple, and it is on these, and not on the atomic theory, that the Periodic Law is based.

The Periodic Law is exerting a stimulating influence on inorganic chemistry in various ways. It is leading to a more careful study of all the elements, with the object of discovering further analogies; new compounds are being prepared and old ones studied better with this in view; new kinds of periodicity are being sought for in physical as well as in chemical properties. The question of the nature of the rare earth metals, the asteroids of the elementary system, as Crookes calls them, is being attacked with greater energy. Are these, of which Crookes claims there are thirty or perhaps sixty, capable of being fitted into the system as it now exists? Must we modify it in order to take them in, or do they represent certain exceptional phases of the evolution of matter from the original protyl, or different very stable modifications on allotropic forms of a few elements? Do the blanks within the system represent existing but as yet undiscovered elements? Do some of them correspond to hypothetical elements, which for some unknown reason are incapable of existence, like many organic compounds which are theoretically possible, but which, if momentarily existing, lapse at once into other forms, or must the scheme be so modified as to exclude them? These are some of the questions raised by the Periodic Law which it belongs to the inorganic chemist to solve. Most important of all is the question of the cause of the periodicity. Before we can hope to establish a mathematical and possibly a genetic relation between a series of numbers, such as the atomic weights and the chemical properties of the elements, we must establish with greater accuracy than heretofore the precise magnitude of these numbers; and it is this that an ever increasing number of atomic-weight chemists is striving to do. The question of the unity of matter is one to a solution of which we are no nearer than ever, and the Peroidic Law in its present form does not afford a proof, or, I think, even a presumption in favor of a genetic relation between the elements. It is quite conceivable that we may have relations of properties without a common origin. With ever increasing accuracy we seem to be removing further and further from the possibility of any hypothesis like that of Prout. The electric furnace, with its temperature of 3,500° C., gives not a sign of the decomposition or transformation of the elements. These questions and the query why we know no elements below hydrogen or above uranium, why the number of the elements is limited, and why there are not as many kinds of matter as there are different wave-lengths of light—all these seem to belong as yet to a scientific dreamland rather than to the realm of legitimate research, yet their solution, if possible at all, will be accomplished only by the labors of the inorganic chemist.

Let us now turn to the more special consideration of the questions of the constitutional formulas of inorganic compounds. The more conservative organic chemists have always been careful to state that the so-called structural formulas are reaction formulas merely; that is, that they are not intended to express the actual relations of the atoms in the molecule, but are merely convenient schemes for rendering possible reactions visible to the eye. Probably most chemists regard them as more than this, as actual diagrammatic representations of the way in which the atoms are combined. The formula of marsh gas, for example,



is regarded as more than a visualizing of its chemical properties; it implies that the carbon atom is an actual physical link between the hydrogen atoms, which are combined directly with the carbon but not with each other. Stereochemical formulas are confessedly more than reaction formulas, and the steric conception of the so-called double and triple union asserts that these actually exist in the sense the words imply, and are not merely names for unknown conditions.

Many of the simpler organic structural formulas unquestionably have an enormous mass of evidence in their favor, but many others we must be on our guard against taking too seriously, and must for the present regard as nothing more than reaction formulas. That we can regard any of them as well established is due, more than to anything else, to the almost invariably constant tetravalency of the carbon atom. Unfortunately, the valency of many of the elements entering into the composition of inorganic compounds appears to be extremely variable and uncertain, and this has greatly impeded the study of the structure of these bodies. The inorganic chemist has been far too prone to assume that the structural theories of the organic chemist are of universal applicability, and, having once for all attributed a certain valency to an element, has been often content with devising structural formulas which have no better claim to recognition than that all the so-assumed bonds are "satisfied." At other times a particular valency has been assumed for no other reason than that it enabled him to contrive a formula for the special case under consideration. The books treating of such matters frequently exhibit wonderfully ingenious inorganic structural formulas which are wholly devoid of a reasonable amount of experimental evidence and which are, therefore, often nothing but pure rubbish. With many inorganic chemists, formula worship has degenerated into fetishism. Let us consider a few examples. For nitric acid, one of the simplest and most familiar inorganic compounds, several constitutional formulas may be written, in which the hydrogen is directly united to the nitrogen or separated from it by one or two oxygen atoms, and in which nitrogen may be either tri- or pentavalent. Some of these are given in the books as if they were gospel truth. Brühl, who has investigated the question by physical methods, suggests that the hydrogen atom is not directly united to any part of the NO_3 radical, but is rotating around it and possibly combined with each oxygen atom in succession, a view approaching that of Werner. There are at least five formulas proposed for this simple acid. For the familiar potassium chloroplatinate, K_2PtCl_6, there are four constitutional formulas seriously advocated at present. It may be $K_2{=}PtCl_6$, with octavalent platinum;

$$\begin{matrix} KCl{=}Cl \\ KCl{=}Cl \end{matrix}\!>\!PtCl_2,$$

with tetravalent platinum and trivalent chlorine, as required by Remsen's theory; $(PtCl_6)K_2$ in the sense of Werner's theory, the two potassium atoms being combined with the $PtCl_6$ as a whole, or it may be a molecular compound in which two molecules KCl as wholes combine with $PtCl_4$ as a whole. The formulas suggested for most minerals are pure guesswork. The silicates are usually written as if containing the group $Si{=}O$, by analogy with carbonyl, $C{=}O$, yet there is not a single silicate in which this assumption rests on any experimental evidence, and the little we do actually know of the chemical behavior of silicon speaks against it. Such formulas, if not purely speculative and devoid of all basis and all value, as they frequently are, at best do not represent structure in the sense that the best established organic formulas do: they are at most reaction formulas only, or they represent partial molecules, in the same way that CH may stand for benzene (C_6H_6) or HPO_3 for a metaphosphoric acid. The attempt to interpret the double salts and halides, the compounds with water of crystallization or hydration, the metal-ammonias, the peculiar compounds of the zeolites described by Friedel, and other so-called molecular compounds, in the sense of the valence hypothesis, seems almost hopeless without taking such liberties with it as to render it nearly useless, and without making assumptions of very narrow and limited applicability. One may well question whether this hypothesis must not be very considerably qualified before it can be taken as the basis of a general theory of the structure of inorganic compounds.

One of the most striking indications of a revival of inorganic chemistry is the recent attempt of Werner to break away from the bonds of the organic structure theory as applied to inorganic compounds and to establish a more general theory in which valency plays a comparatively insignificant rôle. The arguments on which Werner's hypothesis is founded are too numerous and elaborate to be presented here. Suffice it to say that it was primarily based on that peculiar class of bodies known as the metal-ammonias, consisting of metallic salts, combined with usually six or four molecules of ammonia, and in which the ammonia may be wholly or in part replaced by pyridine, water, acid radicals, and other groups. These groups are supposed to be arranged symmetrically about the metallic atom, forming a radical, which, according to its nature, can combine *as a whole* with metals, halogens, or other positive or negative groups. Thus, in the compound $CO(NH_3)_6Cl_3$, cobalt forms with NH_3 a radical, which combines as a whole with the three chlorine atoms; in $(PtCl_6)K_2$ the two potassium atoms are combined with the whole group $PtCl_6$ and not attached to any one part of it; the same applies to $(NH_4)Cl$, and to $K_2(SO_4)$ and $K_4(FeCN)_6$. In the formation of these radicals the bivalent NH_3, the neutral H_2O, and the univalent Cl can replace each other indiscriminately; the valence theory is, therefore, practically thrown overboard entirely and in place of combination by bonds we have an extension of the old theory of molecular compounds applicable alike to the metal-ammonias, the ordinary oxygen salts, the double halides, and the compounds with water of crystallization. It is yet too soon to predict the future of this hypothesis, which has already won numerous active adherents. It is scarcely too much to hope that it will lead, perhaps with some modifications and extensions, to a more comprehensive theory of structure, and to a clearer definition of the as yet only vague conception of valency. It is the broadest generalization of inorganic chemistry since the discovery of the Periodic Law, and shows that inorganic chemists are no longer willing to be mere imitators and to close their eyes to the existence of whole groups of bodies which do not tally with current theories, and are beginning to see that in these is to be sought the key to a broader inorganic chemistry.

The slow development of inorganic chemistry during the period from 1830 to 1865, as compared with that of organic chemistry, was due, as has been seen, in part to the greater breadth and greater diversity of the field, to the relative absence of leading ideas and leading motives, and to the comparative tractability of carbon compounds as compared with inorganic compounds under the restrictions of the experimental methods in vogue. Prout's hypothesis and allied speculations gave a working hypothesis for a limited number of investigators, but the uncertainty of the atomic weights, which in part was conditioned by the imperfection of analytical methods, prevented any satisfactory results being reached. Absolute purity of materials and absolute accuracy of analytical methods are not of the first importance to the organic chemist, to whom errors of one or two points in the first decimal are seldom of any significance. To the atomic-weight chemist, on the contrary, accuracy is the very first point to be considered; not only must his material be absolutely free from impurities, but his methods must be beyond criticism, and it is only with the increasing perfection of analytical methods, admitting not only of quantitative determinations of the greatest accuracy, but also of the detection of traces of impurities which for ordinary purposes are negligible, that this kind of work has offered inducements to a large number of workers. The long-wanting leading idea or motive has been in large part furnished by the Periodic Law. The comparison of the chemical and physical properties of the elements and their compounds, the search for new elements, the fuller investigation of those already known, with the view of more firmly establishing their place in the system, and the redetermination of the atomic weights, are evidence of its influence. Witness, for example, the great activity in the subject of the rare earths, the work on the relative position of nickel and cobalt in the system, and the investigations of the atomic weight of tellurium, having for their object the decision of the question whether this element actually has an atomic weight greater than that of iodine, as the best determinations thus far seem to indicate, or whether it is less, as its chemical analogy to sulphur and selenium requires.

Organic chemistry, with its limited range of temperature, is essentially a chemistry of the beaker, the Liebig condenser, and the bomb oven; it demands but comparatively simple and cheap apparatus of glass, not calculated to withstand high temperatures, and as such is within the means of the humblest laboratory. The reverence of the organic chemist for the platinum crucible is something astounding. With improvements in apparatus for producing and materials for resisting high temperatures, new vistas have opened to the inorganic chemist, while the province of the organic chemist, limited as it is by the instability of his compounds, has derived no benefit therefrom. Not only do we owe to this the beautiful investigations of Victor Meyer and others on high-temperature vapor densities, but with the recent development of electrical technology the electric furnace has appeared, and with it a new chemistry, the chemistry of a temperature of 3,500° C. Not only have new compounds been made which can not be produced at lower temperatures, but the accessibility of many elements and compounds has been greatly increased. The reductions which Wöhler and Deville effected gram-wise in glass and porcelain tubes can now be carried out in the electric furnace pound-wise and even ton-wise. The manipulation of the current for electrolytic purposes, rendered possible by increased knowledge of the laws of electricity, as well as by ease of its production, is yielding results chiefly in the domain of inorganic chemistry, while the organic chemist is but tardily utilizing the current as a means of oxidation and reduction. Besides the extraordinary development of electro-metallurgy, the preparation of soda and chlorates and other technical processes, the application of electricity to purposes of analysis and for the synthesis of new compounds, such as the rare metal alums, percarbonic and persulphuric acids, and the isolation of fluorine, may be mentioned.

Passing to the opposite extreme of temperature, we find the development of high-temperature chemistry accompanied by the growth of a chemistry of low temperatures. The very recent improvements in the art of producing cold have made liquid air a cheap material, and with its aid Ramsay has been able to fractionally distil liquefied argon and to separate from it the contaminating elements of the same group, neon and xenon, as well as krypton and metargon.

The part played by the spectroscope in chemistry is more or less familiar to everyone. From the further development of the science of spectroscopy it is clear that inorganic chemistry has much to gain. Whether or not the view first suggested by Clarke and long defended by Lockyer be true, that the elements undergo partial decomposition in the stars and nebulæ, it is upon this instrument that we must rely for our knowledge of the high-temperature chemistry of these bodies, a chemistry which is wholly inorganic.

The rapid growth of these sciences into which chemistry enters is producing an ever increasing demand upon the chemist for new researches. While the biologist must rely mainly on the organic chemist for his chemical data, no less must the mineralogist and geologist appeal to the inorganic chemist for the solution of many problems in their field. The formation and decomposition of minerals, the disintegration of rocks, the behavior of rock magmas, the phenomena of metamorphism, of ore deposition and vein formation, the influence of high temperatures and pressures—all these afford problems the solution of which is hopeless without the assistance of inorganic chemistry either alone or aided by physical chemistry. The chemist who has to meet the inquiries of the geologist, and who must too often confess our ignorance of the causes of even the simplest phenomena, can not help feeling what a splendid field is here open, awaiting only the advent of workers suitably trained and of laboratories properly equipped for research in chemical geology. The demands of the geologists are unquestionably destined to be among the most potent factors in the revival of inorganic chemistry.

It is not to be expected, nor is it to be desired, that inorganic chemistry will at once sweep organic chemistry from its position of preëminence. The causes to which this is due may outlast our generation, but that the inorganic tide is rising, and that this branch will finally attain its due position, can not be doubted. The recent establishment of a Zeitschrift für anorganische Chemie, while it may be deplored as increasing the already too great number of chemical journals, and as tending to widen rather than diminish the gap between the organic and inorganic branches, is helping to produce a feeling of solidarity among inorganic chemists which never existed hitherto. Even in Germany, the stronghold of organic chemistry, the address of van't Hoff is exciting wide interest, and the Chemiker-Zeitung, in urging the establishment of independent chairs and laboratories of inorganic chemistry, is advocating what will in time unquestionably be realized.

Inorganic chemistry is fortunate in that its renaissance is coming about at a time when physical methods are in vogue. The prediction of

Du Bois-Reymond is being realized; with the aid of physics it is attaining an insight into the dynamical aspect of the science which it could never have reached unassisted. But it is not alone by supplying new methods and suggesting new points of view that physics is aiding the revival of inorganic chemistry. Perhaps equally important is the fact that the rising school of physical chemists, unhampered by the traditions and limitations of organic chemistry, is finding it necessary to explore the whole range of the science in search of material for its investigations. The physical chemist is neither organic nor inorganic, or rather he is either, according to his requirements, but it is precisely because the inorganic field is wider and less developed than the organic that his demands are more likely to be productive of activity.

Energetics is now the basis of chemistry, and it is to be expected, therefore, that inorganic chemistry will not, in the future, have to pass through a period of arrested development and formula worship, such as have so long affected organic chemistry. There will always be compound makers, but their aim will be, not the establishment of constitutional formulas alone, but the study of the laws of chemical energy and the solution of the problem of the nature of matter. We may expect, too, that the still sharp line of demarcation between inorganic and organic chemistry and between dead and living matter will disappear. The inorganic chemist may not affect the synthesis of a proteid, but he will be able, with his wider knowledge, to contribute more to the solution of the problem of the nature of life than any amount of structurizing and synthesizing alone can do. To comprehend life we must understand carbon, but we can no more fully comprehend carbon without an understanding of the other elements than we can explain the earth without a knowledge of the other planets, or man without a knowledge of the fish. He, then, who pursues inorganic chemistry is not only contributing to a higher development of our science than can be reached by the study of carbon compounds alone, but is perhaps doing as much as the organic chemist toward realizing one of the greatest aims of research—the comprehension of life and its explanation in terms of physical science.

SCIENTIFIC BALLOONING.[1]

By Rev. John M. Bacon.

The story runs that early in the eighties of last century two young gentlemen in Paris were trying to make a paper bag float in the air by filling it with smoke, in which attempt they met with extremely limited success. Kindling light fuel in a tin plate and holding the bag above, the latter became distended and bouyant until removed from the flame, when it promptly collapsed. This experiment, however, was witnessed by their housekeeper, who coming into the room at the moment, naïvely asked the young philosophers why they did not tie the tin on at the bottom.

That old lady deserved undying fame. Her idea it was that launched the first balloon into space; yet her name is lost to history. Such is the way of fate. Columbus discovered America, yet the name of the new world was borrowed from a man who remained at home and wrote a book. Anyway, it is a fact that the Mongolfiers are credited with the invention of the hot-air balloon, and to their perseverance certainly is due the first successful step in aeronautics.

A machine to float in the air was from this time an accomplished fact. The world was electrified. No sooner had the first adventurers reached the clouds than everyone indulged in extravagant speculations as to the wealth of new knowledge that was thought to be brought within reach. A new kingdom had been discovered, boundless and unfathomed, and heaven itself had been almost taken by storm. Man had yet to be taught that he could penetrate but a very little way into these new realms and live, and that he was powerless even to guide his course. A few stubborn facts were learned, a few brave lives were lost, and then soon some sort of scientific and systematic investigation was set on foot.

In the first years of the present century the Emperor of Russia bade one Professor Robertson to go up and determine many things. He was to discover how the magnetic needle behaved at a great height; how much electric matter existed there; how a prism would act; how a bird would fly; with many other such inquiries, which, however, led to no results of value.

[1]Reprinted from the Contemporary Review, December, 1898, by permission of Leonard Scott Publication Company.

The like task of rudimentary research was now transferred to France, but with more method, and Gay Lussac got up into regions not less than 4 miles above the earth, where, among other things, he bottled off air, and bringing it down to his laboratory, examined and declared it unaltered. About this time, also, some meteorological observations of interest were carried out during ascents which were creditable if only for the altitudes attained. But the crowning enterprise of this period was the famous *Nassau* voyage of the immortal three who in the year 1836 made a night journey from London to the heart of Germany by an untried way, and in the face of such risks and chances as of their kind had never before been confronted.

The undertaking was due to the enterprise of the leader, Mr. Robert Hollond, its successful issue to the skill of an aeronaut, Mr. Charles Green, while the record of the night's adventure is graphically recorded by the chronicler of the party, Mr. Monck-Mason. Doubtless aerial navigation received a great impetus from an exploit of such daring, and it will be hardly out of place to give one example of such incidents as the night brought with it, which will serve to show the lack of experience and knowledge of the craft then existing.

It was about 3.30 in the early morning when their balloon, which had recently been lightened by a discharge of ballast, was suddenly found to have attained the unexpected height of 12,000 feet. At the same moment, while all around was wrapped in the very darkness and stillness of death, just above them came the sound of an explosion, followed by the rustling of the silk, and a moment later the car received a violent jerk. The party held their breath, while the same thing happened a second and a third time, and then all was still. At this they were seized with the conviction that away up in that awful region, in the dead of night, the balloon had burst and that they were falling headlong to the earth. The explanation, unknown to them at the time, was this: When flying low the balloon had contracted and elongated, and its moisture-laden net must have frozen round it hard as steel. Then on its rising and swelling out again into its globular shape, the frozen ropes had bent to their new position with a crack and a bang, and jerked the car in so doing.

No real mishap occurred, the famous voyage being as successful as it was daring; and from that time onwards we may transfer our sole attention to English enterprise, and in particular to the famous career presently to be borne in partnership by Messrs. Glaisher and Coxwell.

If Tennyson was a born poet, Coxwell was born an aeronaut. He could not exist in any other path of life, and in the very face of fortune quickly took first rank in his profession; while Mr. Glaisher, from early years a trained observer and blessed with a zeal and perseverance seldom equaled, literally threw his life into ballooning ventures in the cause of science. His review of the task he undertook, its difficulties, and at the same time its possibilities, is a commentary on his working years. He speaks of the realm of air, his future hunting ground, as the "great laboratory of changes which contain the germ of future discoveries open to the chemist and meteorologist, as teaching the relation to life of different heights, and as holding within its nameless shores a thousand discoveries to be developed in the hands of physicists." We shall have occasion repeatedly to refer to his methods and the harvest of results secured by his researches.

A word should here be said as to the capabilities of a balloon as a craft to navigate the sky, and it should be remarked that Mr. Glaisher himself was fully persuaded of the futility of any self-contained mode of steering. A vast amount of ingenuity and speculation had been bestowed upon this problem, which, experimenters had failed to see, admits of no solution. It is easy to understand how theorists might start on false premises and entertain conceptions that were hopeless of fulfillment. A bird flies at will through the air, a fish directs its own course in the stream; hence it was urged that a balloon should be capable of guidance. The essential point overlooked was the radical difference between a creature endowed with enormous natural powers of propulsion relative to its size and an inert balloon in the nature of which the application of adequate mechanical power is an impossibility.

Let us examine the two cases. A salmon impelled by the exigencies of nature will swim for miles against the force of a mountain stream, and even leaping the waterfall will stem and struggle through the very torrent falling headlong from above. But conceive the fish's bulk compelled to assume the spherical form of a balloon and the creature at once acquires an irresistible tendency to gyrate, while to proceed in any way different from the rate and direction of the stream would need its muscular exertion increased a hundredfold. On the other hand, conceive a balloon of given capacity built on the lines of a fish, and a moment's consideration will show that you have then only a perfectly unwieldy craft of inordinate length, and, on the very face of it, more completely than ever at the mercy of the wind. Given a balloon poised and in dead calm, and theoretically the aeronaut could propel it in any direction by the mere aid of a lady's fan, but "when the breezes blow" the machine becomes simply an integral part of the general drift, like the leaf in the stream, and is hurried onward literally on the wings of the wind. It needs no pointing out that a ship under sail bears no analogy soever to a free balloon. The ship is propelled by the motion of the air, while it is held under control and guidance by the restraint of the water; but furnish a balloon with both sails and rudder and, freely in the wind, it is obvious that the first will add nothing to its speed, and the second will in no way affect its course.

In the one case only of when a balloon is flying so low that a trail rope can be made to drag on the ground, it can be and has been made subject to some measure of guidance. The objections, however, to thus retarding the balloon's motion and of fettering it to earth are obvious, to say nothing of the consequences liable to ensue when such a method of procedure is adopted across private property.

The only direction in which we may look for any true navigation of the air would seem to lie in the construction of aeroplanes, or floating machines, operated by engines of great power and relatively extremely small weight. Until such an engineering fact may have been accomplished the attention of aeronauts must be chiefly devoted to the study of air currents, and the force and drift of prevalent winds, and with regard to this a great deal of important information is already to hand which should be duly noted.

As far back as 1840 Mr. Charles Green, of whose skill as an aeronaut we have already spoken, gave it as the result of his experience, gained in 275 ascents, that, under all circumstances, "at a certain elevation, varying occasionally, but always within 10,000 feet of the earth, a current from the west, or rather from the north of west, invariably prevailed." Indeed, so firmly impressed was he with the correctness of his observation in this respect that he proposed to attempt a balloon flight from America to England, in which he was confident of success. A very few years later we find Mr. Wise, the then equally famous aeronaut on the other side of the Atlantic, seeking with like confidence to put the same project into effect.

But, naturally, where such constant winds prevail there must be compensating currents found elsewhere, and in actual fact at varying heights; but within a very few miles of the earth currents are often to be met with blowing from every quarter in the heavens.

It was during the memorable *Nassau* voyage already mentioned that Mr. Green turned his knowledge of such currents to account in a remarkable manner. Night was coming on apace, and after passing Canterbury with the sea close ahead it was noticed that their balloon had come under the influence of a change of wind that would bear it out to the German Ocean. But their skipper had already mapped out the drift of accessible currents, and consequently rose to the height he deemed needful, with the result that he at once regained his due course. Mr. Monck-Mason writes of this that "nothing could exceed the beauty of the maneuver or the success with which the balloon acknowledged its influence."

A very similar experience befell the present writer during the past summer in a scientific excursion made in company with Dr. R. Lachlan. The ascent took place in the sheltered grounds of the Crystal Palace, where the true force and direction of the wind could not well be estimated, but at a few thousand feet a moderate current was reached making steadily for the southeast. After a while, however, on descending near the ground for a few moments over Bromley, and again rapidly ascending, the balloon was found considerably out of her course, but again took the former direction due to the higher current. After three hours the coast of Sussex was sighted fast approaching, and it became a question in the mind of the aeronaut, Mr. Percival Spencer, whether it would be practicable to cross the channel. The project was eventually abandoned, but not until the outskirts of Hastings were reached, and the old part of the town lay right ahead, stretching down to the bare cliff. At this point, therefore, it might have seemed impossible to avoid either descending on the house tops or being carried out to sea. The altitude was over 8,000 feet when Mr. Spencer first pulled the valve rope, and the houses were already vertically underneath. The descent not being rapid, the balloon still sped seaward until it neared the forest of chimney stacks around. Here, however, it was caught by a breeze blowing stiffly from the west, and rapidly clearing the town was brought to earth in Fairlight Glen. The stratagem was simply a display of perfect judgment on the part of the aeronaut, who, noting and calculating accurately the ground current, had piloted his craft to a convenient spot which he had fixed on from nearly 2 miles high.

As may be presumed the depth of different currents varies vastly, but it is very common to meet with a change of direction before the first thousand feet is reached. Since, then, such fluctuations are all important, and also all primarily due to relative temperatures, it becomes the first care of the scientific aeronaut to record continuously all changes of temperature observed at different heights, on different days, and at all hours of the day and night. For, regulated by such differences of temperature, seen or unseen columns of warm moist air, or mist, will constantly rise off valleys, or woods, or crops, while return supplies of cooler air will filter down to earth from above, and in this way a remarkable condition of the atmosphere, which needs to be investigated to be fully realized, may be brought about.

Late in the evening and far on into the night the explorer of the upper regions may encounter, at varying and uncertain heights, tracts of warm and genial air whose existence could not be detected from below, or, indeed, from any observations made on mountain slopes. Mr. Glaisher gives an interesting experience of an ascent of some 6,000 feet which he made over verdant Surrey, on a late May evening just before sunset, and repeated again immediately after sunset. Starting on the second ascent at ten minutes past 8 the temperature was 54°, and on his ascending this steadily declined, but not so rapidly as in the ascent prior to sunset, so that at the height of 6,200 feet the temperature, though only 35°, was 6° warmer than it had been three-quarters of an hour previously. On descending to 4,500 feet, however, it had increased to 37°, from which point it went up by leaps and bounds, registering 47° at 1,500 feet and 54° at 900 feet, below which height it again declined till earth was reached.

In a night ascent at the end of September the present writer recorded similar, though somewhat more changeful, observations.

Leaving the earth at 9.30, the temperature rose rapidly up to 500 feet, at which elevation a colder stratum was encountered. In another hundred feet warmer air was again met with, after which a second and a third cold stratum was found and passed, beyond which the air grew sensibly warmer, reaching 50° at 6,000 feet, that is, some 15° higher, probably, than the earth temperature at that moment.

The question, then, here arises, Do warmer layers exist above as true strata, or are there rather, floating aloft and all unseen, detached masses of a warmer air, which, if visible, would resemble a mottled, or patchy, or stratified sky? This point will be discussed later in relation to certain phenomena of sound.

It is clear, however, that though the diurnal rise and fall—the vertical ebb and flow, as it were—of atmospheric currents near the earth's surface is a most important factor demanding thorough examination, it is yet more needful to trace, by all means available, the vaster and more general lateral sweeps of the ocean depths above. Valuable information respecting such winds as play over a large continent has been gathered from systematic observations made with high flying kites in America, where confirming those views of aeronauts already mentioned, it has been found that at considerable elevations the kites have usually encountered winds blowing from the west while a daily rotation of shallower winds prevails below. A remarkable characteristic, moreover, met with is that where the direction of such winds changes, the change may be perfectly abrupt. It has, indeed, been recorded by scientific balloonists that they find, in the regions where winds of different directions pass, that one appears actually to drag against the surface of the other, as though tolerating no interval of calm or transition; and yet a more striking fact is that a very hurricane may brood over a placid atmosphere with a clean-cut surface of demarcation between calm and storm.

Mr. Whymper, watching an eruption of Cotopaxi from a station 60 miles distant, observed a violent uprush of inky vapor ascend quite vertically through serene air till, as he judged, it had reached an altitude of 20,000 feet above the crater, or twice that height above sea level. At that point it "encountered a powerful wind blowing from the east, and was rapidly borne toward the Pacific, seeming to spread very slightly, and presenting the appearance of a gigantic ┌ drawn upon an otherwise perfectly clear sky. It was then caught by wind from the north, and, borne toward him, appeared to spread quickly."

It is not only, however, when winds cross at different heights that this remarkable close restraint within their own limits is to be noticed. Even on the same level contrary winds will maintain their distinctive flow more determinedly than cross currents of water amid stream. Thus, Mr. Charles Darwin found on mountain heights winds turbulent and unconfined, yet holding their courses like "rivers within their beds;" so again the French aeronauts, MM. W. de Fonvielle and

Gaston Tissandier, use almost the same expression in describing "a warm river which flowed for a whole month over the clouds."

We may thus draw an outline sketch of the movements of the great atmospheric ocean, its tides, its streams, and torrents, but a just examination into its constitution goes further than the consideration of temperatures and currents. Fully as important as either is the question of humidity, while no records with which the aeronaut has had to deal are more curious or more instructive than those that come under this head.

Going back to the times which witnessed the early exploits previously mentioned, we find Mr. Monck-Mason formulating a theory that when rain falls and sky is overcast there will be further cloud layers above, while on the contrary, when no rain falls and the sky is overcast, there will be blue sky above. Thirty years later Mr. Glaisher records an ascent which, while lending confirmation to this theory, supplies other noteworthy observations. It had been a calm, brilliant, and promising June morning till noon, when, in a manner common enough in our summers, clouds had suddenly blown up and darkened the sky so forbiddingly that a very hasty departure was made, and, with great lifting power, his balloon rose 4,000 feet in four minutes. Passing through a cold, damp cloud at that height, he found, contrary to his expectations, farther clouds above, and at 9,000 feet the air was full of the sighing of the wind that presages storm. At that point, however, the sun shone momentarily, encouraging the belief that clouds would soon be passed. But instead of this the balloon again ascended into fog mingled with fine rain. The experienced aeronaut and meteorologist now seems to have become fairly astounded at his results. At 12,000 feet he entered a wet fog, growing drier at 15,000 feet; then the sun peeped out, and then again came wet fog. A thousand feet higher the fog was dry. A thousand feet higher yet the sun once more gleamed for a moment, and then gave place to fog, growing wetter, but soon passed. At 20,000 feet dense clouds were still overhead, fringed and watery, while but a little higher patches of blue sky appeared with floating cirrus far above.

Contrasting with this may be recorded the register obtained during the late exceptional summer by the writer in a series of ascents in afternoon and night hours from the Crystal Palace, from Newbury, and from Clifton, which showed consistently an almost uniformly dry and thirsty condition of the atmosphere up to the highest altitude reached; and where clouds were met with they were fast thinning away. Wandering cloudlets would wend along and vanish into air, like the steam of a passing train. There was, however, one notable exception during an evening in mid-September, when, traversing Somersetshire at an elevation of 3,000 feet and upward, the air, though remaining clear as before, had become saturated with a moisture unseen and unsuspected, but which proved the true herald of the short break that immediately after occurred in the hot, dry season.

A fair indication of the moisture present in a clear heaven may, perhaps, often be found in the tint of the blue sky—toned to gray in dry, east winds, pale during continuance of drought, and deep blue when storms are imminent. However, enough has been said to show that we must, as a general rule, by no means regard even our clearest skies as homogeneous or uniform. Moisture will lie around or above in pools or shallow seas, and close observation in addition to delicate instrumental aid is needed to measure even approximately its varying constitution. But there is a subtler test that now claims our notice, and which is capable of far greater development than has been accorded to it. A few records gathered from a long series of observations will introduce and justify this new division of our subject.

From a high ridge in Berkshire there is occasionally to be heard the sound of the firing of guns at Aldershot, 30 miles to the eastward. These guns are chiefly noticed in the summer time, when there is very rarely an east wind to help the sound. Occasionally the reports are mistaken for distant thunder, and thus cause alarm at a time when hay harvest is in progress. There is, however, a saying in the district that the "guns are worse than thunder," and this because they forecast not a passing or local storm, but rather the approach of generally unsettled weather. It is easy to prove that it is a continuity of an uniform moisture-laden air stretching across that part of the country that is the cause of the phenomenon. The testimony of seamen and other trained observers goes to show that homogeneous moist air or mist is the readiest vehicle of sound; that dry air seldom or never conveys sound so readily; while an atmosphere of varying density renders all sound capricious.

From a sheltered quiet lawn the Aldershot guns had not been noticed all through the late summer until far on in one afternoon in the middle of August, when their sound rolled out with great distinctness, the weather to all appearance remaining unchanged and the barometer standing firm and high. In the night, however, thunder was heard for some two hours, the first time for many weeks, and in the morning the guns were heard again more distinctly than before. In this case sound had been the clearest, and, indeed, the only telltale of a humid layer of the atmosphere brooding over the countryside.

Arguing, however, by the light of such statistics as have been given above, there was no proof here of the true condition of the air at higher elevations; but, as it happened, only three days previously, the writer, during an aerial trip, had had occasion to note some remarkable acoustic conditions prevailing aloft. Weather conditions, as indicated by hot suns and clear skies, by readings of temperature and pressure, remained, indeed, unchanged, but there had been indications of disturbance overnight, and at Earl's Court, for two hours before closing time, the captive balloon had had to be hauled down. Still on the day in question there was nothing of a nature unusual save a fitful, gusty wind, and, perhaps, a feeling of languor in the air.

The ascent was made at 4 p. m. from the Crystal Palace, and the balloon's course lay directly over London at a mean height of 4,000 feet. The thermometer indicated nothing abnormal, there being a fall of half a dozen degrees in the dry bulb, and an amount of general moisture, shown by the wet, comparable with that recorded below previously to starting, only fluctuating constantly within small limits. One matter of consideration only was remarkable, namely, sound, and this was noteworthy by its absence. The cheer of the crowd lost its wonted heartiness, lesser sounds were mute, even whistles forgot their shrillness, and the raucous rattle of the giant city was reduced to a mere dull hum. But not till the quiet country to the north of London was reached did the full measure of acoustical opacity in the atmosphere betray itself. This is well tested by means of echo. A hunting-horn forms a convenient instrument for evoking echoes, and very frequently it is easy to hear the sound of a blast returned to a balloon across an interval of upward of 2,000 feet. Of course the nature of the country over which the aeronaut is traveling at the moment greatly influences the result. The waves of sound recoil from trees more readily than from fields, most readily of all from the surface of still water; but days have been found when fields in open country, irrespective of their character, have clearly responded to the horn, though lying a full half mile below. There was, then, much significance in the fact that on the day now being described echoes refused to be aroused even at the range of a few hundred feet. The explanation apparently lay in the unequal nature of the medium through which the sound had to travel. The air was presumably, as it were, broken up in patches, and barred the passage of sound much as glass when broken up will impede the passage of light. We may, indeed, conceive the air to have been invisibly mottled, after the manner, say, of a finely divided mackerel sky; a transient condition of things, no doubt, and we apparently see how three days later the moister masses had settled in a general low-lying layer.

We may here note that Mr. Glaisher's published statements with regard to sounds heard from a balloon are interesting and valuable. He reports that the whistle of a train is audible at 10,000 feet, the train itself at 8,200; the bark of a dog at 5,900; shouting of men and women at 5,000, and so on; but since the writing of that report, atmospheric refraction and reflection of sound have become established facts. So also the strengthening of sound by resonance; its extinction by interference, and that curious modification it occasionally undergoes whereby the same sounds may vary in relative intensity on different days.

No more important inquiry can come within the province of the aeronaut than as to the mode and measure in which his own proper element conveys the sounds we hear, and mayhap quenches those sounds we don't hear. Some avenue of sound through the void below has sometimes admitted, for a moment only, the strains of a band or clang of a bell, which the next moment has been lost utterly. Sometimes, far beyond its proper range, some noise from earth has been caught in the hollow of a cloud, as by a sounding-board, and concentrated loudly upon the ear of the balloonist. Sometimes an intervening cloud far down has damped the roar of a train more effectually than even the mass of a hill has done, when the train had been burrowing through a tunnel.

In all cases, with one possible exception, sounds heard aloft lose reverberation. Mr. Whymper describes thunder on the mountain side as uttering a "single bang," so to a voyager in the sky will a gun on Plumstead Marsh speak with a single yelp. But Professor Tyndall, on one occasion, convinced himself and those who stood around him that reverberation could be found in empty air, and that echo can be returned from an acoustic cloud invisible to the eye. This interesting point is being investigated by the aeronaut, with results that will shortly be more complete. Unquestionably the entire physics of the firmament will shortly have undergone the closest scrutiny, its composition, the proportion of newly found constituents at highest accessible elevations, the amount of carbonic acid it holds, the measurements of its electricity, the condition and character of matter in suspension, the presence or absence of germs. These are questions all important, and on which many facts have been amassed, but on which it may be premature to generalize.

The balloon has now to be recognized as an indispensable observatory. In some ways it affords the student of astronomy and optics opportunities which can not be gained in any station on earth. The extraordinary brilliance and steadiness of celestial objects viewed by optical aid from a balloon 10,000 or 12,000 feet above sea level must be seen to be realized. Indeed, from half that height the full moon, regarded through an ordinary field glass, becomes an object intolerable to gaze upon. But the case is far otherwise on mountain observatories, which can not be wholly free from disturbing currents or from that peculiar stratum of air always and everywhere clinging to earth.

It is obvious, then, how many questions can be dealt with to great advantage from higher and purer regions. Most important data are being gathered bearing on refraction as influenced by altitude, by temperature and humidity. Spectroscopic observations taken from the earth, and again a few minutes later from some thousands of feet above, are destined to throw very valuable light on those lines which have simply a telluric origin. Again, many doubtful observations needing low powers, and hitherto made from earth, will receive a crucial test when repeated from above; and rare phenomena, such as a total solar eclipse or shower of meteors, too often hid from the observer below, can hardly escape the view of the voyager above the clouds. It is even reasonable, indeed, to hope that the corona may be photographed without eclipse.

Some little special training, no doubt, is needed in the observer himself. He has to grow accustomed to the somewhat cramped quarters within which he is confined; not less to the novelty of the situation and to the fact that his observatory seldom remains for a single moment in any one position. He learns only by experience not to encumber himself with superfluous apparatus and not to attempt too much or too varied work on any one voyage. It is noteworthy, too, how much incongruity is found in the experiences of different individuals. To one, on ascending, the earth will seem to recede from beneath and hollow itself out, as it were, into a basin bounded only by the horizon. To another no optical illusion is noticeable, and the earth, from all considerable heights, will appear only as a dead level. With many, but by no means all, aerial travelers, when rapidly ascending or descending, there may be a certain feeling of distress in the ears, interfering more or less with the sense of hearing, but transient and generally relieved by the mere act of swallowing.

On clear days, as higher altitudes are reached, all voyagers will be conscious of such sensations as are experienced on mountain heights, the fierce rays of the sun appearing almost capable of blistering the skin, even though the air grow very sensibly colder. There will be few, also, who will not own to a great exhilaration of spirits, which renders the task of concentrating the mind on strict observational work somewhat difficult and irksome. Some striking feature of the shifting panorama, some opening fairy scene in the heavenly glories of cloudland, will almost irresistibly divert the attention.

It is sad, indeed, that these indescribable beauties do not lend themselves readily to photography and can never be done justice to by artist's brush. With the startling suddenness of a transformation scene there will sometimes burst on the view a vision of aerial Alps ot purest snow and limitless in range; towering mountains and deep ravines, rocks with yawning chasms, giving place to true castles in the air with frowning battlements, dissolving in their turn into forests of towers, domes, and spires, and all the while the beholder is conscious that this is not illusion, but a reality of his new home, and that for the time he himself is a naturalized inhabitant of the sky.

Later on fresh conditions unknown on earth will commonly prevail. The sun, hastening to the west, seems loath to withdraw his warmth, and as the distance becomes swallowed up in gloom and shades grow darker beneath there is the feeling that the rawness of evening is absent, and the night grows genial instead of chill.

One special peculiarity in daylight ascents, always more or less pronounced, has to be reckoned with in taking photographs or making visual observations of any scenes below, viz, the haze that veils the lower levels from the traveler aloft. This is a true physical fact, and due to the particles of low-lying matter in suspension, which, presenting their sun-lit surfaces toward an observer above, create a glare to his vision, while to another observer on the earth the same dust motes, presenting only their shaded sides, do not betray their presence save by somewhat diminishing the direct light of the sky. On one occasion, when rising almost perpendicularly to a great height above the Crystal Palace, with the sun bright overhead, dense white cloud wreaths entirely obliterated the scene below, yet visitors in the Palace grounds continued to watch the balloon, but half hidden in what appeared to them only the thinnest summer cloudlet.

Perhaps the most serious drawback to ballooning in our own country is the very limited territory over which it can be practiced. A gale blowing 60 or 70 miles an hour would render a voyager above the clouds soon liable to be carried out to sea without his knowledge, and unless he can see stationary objects below he is usually quite ignorant of his rate of travel. He is, indeed, for the most part unconscious of all wind or of any motion of his own vessel, until, with anchor cast overboard, she at length strikes earth. It is then in rough weather that delicate instruments are apt to take harm. It is then that fellow-passengers, for mutual safety, must stick by their craft and hold on well together. In other words, it is then that the fun begins. And maybe, riding steeplechase with a cripple balloon, bowling over open country before a stiff wind, yields little in excitement to a brush with the Pytchley.

Such, however, must be considered record occasions. The more common experience on descending is to approach the earth with an onward flight no faster than pursuing peasants can run. Speed in general is in proportion to elevation. On the occasion just referred to, the balloon in question remained hovering over the Crystal Palace grounds, and apparently over the same spot in the grounds, for some twenty minutes, till, as altitude increased, the whole inclosure had, to all appearance, shrunk together to the dimensions of a toy model, when the balloon began to draw away at a steadily increasing rate, and reached Rainham in Essex at an average speed of 7 miles an hour.

To pursue aerial travel at its best it will perhaps be agreed that a height not exceeding 3,000 or 4,000 feet will be most convenient, but it must be remembered that a balloon never maintains for long the same altitude. Reaching regions of less atmospheric pressure, and other conditions remaining the same, a portion of gas escapes, causing the balloon to descend until checked by discharge of ballast, when it again changes its motion, and like an unsteady balance, oscillates above and below its true level of equilibrium.

For eye observations of earth no higher altitudes need be desired. Clouds not intervening, the distance for 30 miles will often be distinctly defined while many hundreds of square miles lie displayed on a map in which every detail is delineated, and often thrown into strong relief of light and shadow. Hurrying over town and village, over patchwork fields and wood and river, the shadow of the balloon itself may commonly be traced, and ever and anon stray messages from earth will reach the car. The shriek of a distant train, the hour tolled out from some church tower, even the musical murmur of the woods far down; and though the air around is bereft of bird or insect life, a wandering ball of thistledown may come floating upward borne on some unseen current.

Enough has been said to show the many capabilities of a balloon, while, on the other hand, its disadvantages are far more apparent than real. Its danger is greatly exaggerated. With due care and caution a voyage through the air carries no greater risk than a voyage by sea. Many times from want of care, or else through emergency, a balloon has been brought precipitately to earth, but under these circumstances in far the majority of cases, the collapsing silk has formed a natural parachute and saved the voyagers from harm.

There are other chances, too, in cases of mishap, still in favor of the aeronaut. On one occasion Mr. Coxwell, falling half a mile with a broken valve, landed scathless in an apple tree.

THE TUNDRAS AND STEPPES OF PREHISTORIC EUROPE.[1]

By Prof. JAMES GEIKIE, D.C.L., LL.D., F.R.S.

(With map.)

I.

We are all familiar with the general conclusion arrived at by geologists that our earth has experienced many climatic changes. There have been times when genial conditions ranged up to the highest latitudes, and times also when the cold of the arctic regions descended to what is now our temperate zone. The cause or causes of those remarkable vicissitudes still baffle research. Many explanations have been advanced—some highly improbable, others perhaps more likely, while of yet others it may be said that possibly they contain a certain amount of truth. But no one theory or hypothesis has succeeded in gaining general assent, and we shall not therefore at present concern ourselves with any. In place of reviewing hypotheses and speculations, I shall limit myself to a survey of certain facts connected with the later geological history of our continent, the meaning of which is more or less apparent. The evidence referred to leads to the conclusion that Middle Europe has within the human period experienced conditions such as now obtain in the tundras and barren grounds of circumpolar regions. When these conditions passed away, the central and west-central areas of our continent became steppe lands, comparable as regards climate to the subarctic steppes of southeast Russia and southwest Siberia.

As geologists reason from the present to the past, it will be well to take first a brief glance at those regions of the globe where at present tundra and steppe conditions respectively prevail. When we have realized the salient characters of those regions, and the nature of their floras and faunas, we shall be in a better position to understand the bearing of the geological evidence.

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[1] A lecture delivered before the Royal Dublin Society, March 9, 1898. Those interested in the subject of this lecture will find it fully discussed by Professor Nehring in his work Ueber Tundren und Steppen. See also, for further information and for references to other authorities, The Great Ice Age, Chapter XXXVIII. Reprinted from The Scottish Geographical Magazine, Vol. XIV, Nos. 6 and 7, June and July, 1898, pp. 281–357.

The arctic lands of Eurasia and North America show two well-marked zones—a zone of treeless wastes bordering the Polar Sea, and a coniferous forest zone lying immediately to the south. The treeless wastes are known as tundras in Europe and Asia, and as barren grounds in North America. These form plains of immense extent, but of very unequal width from north to south. In Eurasia they lie for the most part north of the Arctic Circle, while in North America they range upon the whole considerably farther south, reaching the sixtieth parallel on the western shores of Hudson Bay. Their southern boundary, however, is in both Old and New Worlds exceedingly irregular. Where the flat lands are exposed to the full sweep of the northern blasts, tundra conditions advance far to the south, invading the forest zone in narrower or broader stretches. Indeed, even within the region of arctic forests isolated patches and wider areas of tundra are encountered. In other places more sheltered from the fierce winds coming from the polar seas, the arctic forests in their turn encroach upon the tundras, so as nearly to reach the shores of the frozen ocean. Such is the case in the valleys of the Yenesei, the Khatanga, the Olenek, the Lena, and other North Siberian rivers. Similarly in North America the arctic forests straggle down the valleys of the Mackenzie and other rivers to beyond the Arctic Circle.

Mosses and lichens form the prevailing vegetation of the tundras—marshes and bogs extending over vast areas in spring and summer, while the less marshy tracts are carpeted with gray lichens. Here and there, too, in sheltered spots, dwarf birch and willow scrub sprinkle the surface or flourish in denser masses, and ever and anon more or less wide stretches of meadow put in an appearance. Now and again the interminable plains give place to rolling ground, the low hills and knolls being not infrequently clothed with dwarf trees. No hard and fast line, indeed, can be drawn between the tundras and the arctic forests. The two regions not only interosculate, but numerous oases of trees are encountered in the tundras along their southern margin, while equally numerous patches of tundra, as already mentioned, are met with farther south within the arctic zone. It may be added that in northern Siberia bare rocky hills and mountains—highly fissured, and showing many gullies, ravines, and débris-strewn valleys—now and again break the uniformity of a tundra landscape.

A word or two now as to the characteristic animals of the tundras and barren grounds. First among these come the arctic lemmings. They feed on grass roots and stalks, mosses, reindeer linchens, and the shoots of the dwarf birch, for which in winter they tunnel through the turf or under the snow. The banded lemming is an especially characteristic form, since it is confined to the maritime tracts of Eurasia and the adjacent islands, and the corresponding areas of North America, and is never met with in the forest zone. The Obi lemming has a similar distribution, but ranges somewhat farther south, and not quite so far north, as the banded lemming. The arctic fox is another characteristic member of the tundra fauna, having a high northern range. It occasionally wanders south to the sixtieth parallel, but that is only in treeless regions, for it everywhere avoids the forest, seeming to prefer the barest and most sterile lands. Another common denizen of the tundras is the arctic or mountain hare. This is the same species so commonly met with above the limits of the forests in the mountains of temperate Europe. A closely allied form (polar hare) frequents the barrens of North America. The reindeer must also be included in the tundra fauna, although in winter it ranges far into the forest zone. The muskox, formerly a native of Eurasia, is now confined to North America. Like the arctic fox it avoids the forests, ranging north of these from the the sixtieth parallel up to the highest latitudes.

Such are the most characteristic mammals of the tundras. There are many other animals, however, which frequent the same regions, more especially in summer. Among these may be mentioned glutton, voles, ermine, weasel, wolf, common fox, and brown bear. The summer visitors also include a vast host of birds, especially water birds.

The climate of all these northern plains is extreme—the winter temperature falling upon an average to 27° below zero, while in summer the average temperature is about 50° F. The actual range in certain regions is of course considerably greater. These conditions necessarily give rise to annual migrations. Only a few mammals, as we have seen, brave the long winter of the tundras, where river and lake are often frozen solid, and the whole land is sheeted in snow. During the great frosts the air is remarkably still, but as winter draws to a close storms of wind and snow become frequent. Wide regions are then often swept bare, and the snow is blown into every abrupt hollow and depression in the plains, and into the gullies and ravines of the hills, where it becomes so beaten as often to bear the weight of a man. Not only snow, but sand and dust, are thus swept forward. The sand and dust are no doubt largely obtained from the great river valleys and deltas, but no inconsiderable proportion is derived also from the bare rocky hills and mountains, which in many places diversify the surface of the circumpolar plains. Frost is a great pulverizer of rocks, not only splitting them into fragments, but disintegrating their surfaces into grit, sand, and dust. It is remarkable how in the highest northern regions the surface of the snow often becomes discolored with fine sand and dust derived in this way from exposed rock surfaces.

We need not enter into further details as to the physical conditions of the tundras. It will be sufficient to sum up here the points which are most deserving of our attention. Briefly they are these:

1. The climatic conditions of the tundras are extreme, and necessitate annual migrations.

2. The flora is represented chiefly by mosses and lichens. Here and there, however, tracts of grassy meadow occur, while inlets and oases

of dwarf trees and scrub, chiefly birch, willow, juniper, and conifers, not infrequently appear along the southern margin of the tundras.

3. The most characteristic animal forms are lemmings, arctic fox, arctic hare, musk ox, and reindeer. Of common occurrence also are various voles, ermine, and weasel. Their range, however, is hardly so far north, and they go much farther south. So again the wolf, the ubiquitous common fox, and the brown bear, are frequent visitants rather than common denizens of the tundras.

4. In summer many of the animals just named push farther north, while swarms of birds (especially water birds) visit every part of the treeless zone.

5. Lastly, in winter, storms of snow and dust are common.

We may now take a similar brief glance at the steppe lands of Europe and Asia. The regions included under this head show considerable variety. Some steppes are mere desert wastes while others are fertile tracts capable of high cultivation. Many are low plains, others are elevated plateaus, the former having a subarctic, the latter a subtropical climate; and between low and high steppes many gradations are met with. All are more or less characterized by an extreme range of temperature. The steppes with which we are at present concerned, however, are the generally low grassy plains which Professor Nehring designates the subarctic steppes. These occupy wide areas in southeast Russia and southwest Siberia, extending between the middle course of the Volga and that of the Irtysch. It is quite a mistake to suppose that these steppes are throughout all their extent treeless plains. In many places chains and irregular groups of hills diversify the surface, while here and there trees of various kinds, such as pines, larches, birches, oaks, limes, alders, willows, wild apples, and others, are more or less plentiful. Many of the woods are mere oases, extending along the banks of rivers and streams, or clustering around the margins of fresh-water lakes. In southeast Russia the boundary between the steppes and the forest lands is very irregular—the two regions constantly interosculate.

The climate of these subarctic steppes is quite continental, the summer being relatively warm and the winter relatively cold. The average temperature in January hardly exceeds 3° F. while that of July is at least 70°. Again, the rainfall is very uncertain. In some years it is excessive, in others meager, while occasionally it altogether fails. With the approach of spring vegetation rapidly develops, becoming rank and luxuriant, but with the heat of summer it quickly fades and withers away. Severe frost, and frequently heavy snowstorms, characterize the winter. In such areas as are more or less wooded the climate is somewhat less continental, the summers being relatively less dry and the winters not so cold. But even in those wooded regions the seasons are strongly contrasted. In general, we may say the steppe lands in summer are practically rainless. The ground is thus parched and burnt up, so that sand and dust rise with every wind, and as the open plains are often swept by summer búrans, vast quantities of loose materials are transported from place to place, and here and there accumulate in hollows and depressions, or come to rest in the lee of sheltering rocks and hills. In winter, if little snow has fallen, the unprotected ground is similarly scoured by the tempests, dust, sand, and even small stone being carried forward. Thus both in summer and winter sand and dust storms play an important rôle, and loose materials are piled up to great depths in valleys, and in the ravines, fissures, and crevices of the rocky hills.

As a rule these heaps and sheets of drifted sand and dust show little or no arrangement, although now and again some trace of bedding may appear. Should they chance to become well covered with snow in winter, then, when warmth returns and the snow gradually melts away, plants quickly spring up, and the heaps become fixed and cease to drift. It is obvious that not infrequently land shells, and often enough the remains of mammals, must be entombed in such wind-blown materials.

In winter, however, it is snow more commonly than dust that drifts before the wind. The great snowstorms of the subarctic steppes are quite as terrible as those of the tundras. No life can withstand the fury of the blizzards, and many are the disasters on record. Thus in 1827 all the flocks and herds that wandered over the steppes between the Volga and the Urals perished in one great storm. According to the Government report the loss sustained by the Kirghiz amounted to 10,500 camels, 280,500 horses, 30,480 cattle, and 1,012,000 sheep. Not many years pass without some disaster of this kind, and when the snow has melted away, hundreds of cattle, often far strayed, may be found huddled together in one place—some suffocated, frozen, or starved to death, others drowned in the creeks and ravines in which they had vainly sought for refuge from the blast. Now we can readily conceive how the carcasses might eventually be buried under drifted sand and dust, and the bony skeletons thus become preserved for an indefinite period.

Among the most characteristic animals of the subarctic steppes are jerboas, pouched marmots, bobac, pika or tailless hare, small hamster rat, various voles, corsac, caragan fox, manul cat, saiga, dzeggetai, wild horse, etc. Besides these, many other animals are met with in the steppes, but are hardly so characteristic, since they range into adjacent regions, to which they more properly belong. Among them may be mentioned lynx, wild-cats, tiger, wolf, jackal, common fox, martens, ermine, weasel, otter, glutton, badger, brown bear, squirrels, beaver, common hare, mountain hare, wild boar, elk, reindeer, roedeer, stag, etc. Several hundred species of birds frequent the steppes, among which may be mentioned great and little bustards, larks, grouse, buzzards, eagles, owls, etc.

We may now sum up, in a few words, those features and characters of the subarctic steppes which are of most importance from our present point of view.

1. Steppes, like tundras, are not exclusively plains. They include rocky uplands and hills, and are traversed in many places by streams and rivers.

2. Vast expanses are clothed with grasses, while others are more or less sterile and bare. Oases of forests are not infrequently present.

3. The most characteristic animals are jerboas, pouched marmots, bobacs, and others—the mammalian fauna being more varied than that of the tundras.

4. Many animals properly belonging to forest lands and to mountains frequent the steppes.

5. The seasons are strongly contrasted, and the whole region is exposed to dust storms in summer, and to snowstorms in winter.

With these facts relating to existing tundras and steppes kept in view, let us now examine the evidence adduced by geologists to show that tundra and steppe conditions have successively prevailed in Middle Europe.

One of the most remarkable superficial deposits of central and west-central Europe is that which is known under the general term of löss. Typically it is a fine-grained, yellowish, calcareous, sandy loam—consisting very largely of minute grains of quartz, with some admixture of argillaceous and calcareous matter. Upon the whole the quartz grains are well rounded, although often enough they are sharply angular. Frequently the accumulation shows a porous structure, and is penetrated by long, approximately vertical root-like tubes or canals, lined with calcareous matter, which cause the deposit to cleave or divide in vertical planes. Hence it usually forms more or less upright bluffs upon the margins of streams or rivers which intersect it. It is usually unstratified, except now and again toward the bottom of the deposit, where intercalated layers, and even sometimes thick beds of sand, make their appearance. The löss is essentially a deposit of the low grounds, and is well developed in the broad river valleys of western and central Europe, as in those of the Seine, the Garonne, the Rhone, the Maas, the Moselle, the Rhine and its tributaries, the Danube and many of its affluents, such as the Drave, the Save, the Morava, and the Theiss. It also extends as a narrow belt along the southern margin of the great plains of North Germany. It is in southern and southeastern Russia, however, where it attains its widest development, covering as it does an immense tract, stretching west and east between the valleys of the Pruth and the Volga. Throughout this vast region it is usually very dark in color, forming what is known as the black earth.

Without at present going into the question as to the origin of the materials of which the löss is composed, it is obvious enough that they have in some places been arranged by water. Thus here and there, especially at or toward the bottom of the accumulation, distinct traces of bedding may be seen, and the beds have yielded fresh-water shells. This, however, is exceptional. Löss is, for the most part, a subaerial accumulation—a wind-blown deposit. This is shown not only by the rounded character of its minute constituents and by the general absence of bedded arrangement, but by the abundant presence of snail shells and the frequent occurrence of relics of land animals. Its organic remains are essentially terrestrial. Moreover, its particular distribution—the mode in which it occurs—points clearly to the action of prevalent winds. Thus, although it is widely developed over low-lying regions, it nevertheless sweeps up to heights of 200 to 300 feet and more above the bottom of the great river valleys. Not only so, but ever and anon it extends across the hills and plateaus between adjacent valleys, wrapping the whole land, in short, like a mantle. Again, in many places, we find it heaped up in the lee of hills, the exposed windward slopes of which bear no trace of it, while in certain valleys it shows a similar partial distribution.

Among the organic remains yielded by the löss are some that indicate arctic conditions, while others are strongly suggestive of a steppe climate, and yet others tell us of forest lands. It is impossible that all the creatures referred to could have lived side by side in the same region, and annual migrations will not wholly explain their appearance in the same deposit. The evidence leads to the conclusion that the accumulation of the löss must represent a long period of time during which climatic changes took place. Fortunately now and again the lössic accumulations exhibit a succession of faunal zones—different suites of organic remains occurring at different levels. And a similar and corresponding succession has been discovered in many of the caves of middle Europe.

A tundra fauna is the earliest of which we have any record in the löss and in the particular caves referred to, and it is worth while to glance for a moment at the former wide distribution of that fauna in Europe. It will be remembered that two of the most characteristic tundra forms are the banded and the Obi lemmings. Now, remains of both these species have been met with again and again over all central Europe—in Russia, Poland, Austria-Hungary, north and south Germany, north Switzerland, France, Belgium, and England. Sometimes they occur in single specimens, at other times they are extremely numerous, the remains of several hundreds having been obtained at various localities. In many places both species of lemming are found together; elsewhere either one or other occurs alone. The banded lemming, as a rule, has left its remains most abundantly in hilly and upland tracts, while those of the Obi lemming are met with more frequently in low-lying areas—a distribution quite in keeping with that which obtains at present in the tundras. That these arctic animals were not mere passing or occasional visitors is shown by the fact that young and full-grown individuals occur together in hundreds at various places and are associated with the remains of other characteristic arctic animals which breed in the same regions. Thus well-preserved skeletons of arctic fox, having their milk teeth, have been found lying side by side with the bones of the lemmings. As the arctic fox breeds in June, it is obvious that those young individuals must have died in summer.

Our knowledge of the former distribution of the arctic lemmings is no doubt not so full as it will yet be, but already we have ascertained that these creatures ranged as far south as central France and the base of the Alps, in Switzerland, and as far west as Somerset, in England. Besides the arctic fox, many other northern forms were congeners of the lemmings in middle and western Europe, such as mountain hare, muskox, reindeer, glutton, voles of various kinds, ermine, weasel, wolf, common fox, and the now extinct mammoth and woolly rhinoceros. A number of northern birds have also been recorded from the same deposits as those which have yielded relics of the tundra animals. I need mention only ptarmigans, buntings, snow owls, ducks, geese, and swans, all of which are in harmony with the arctic character of the mammals, since the same forms are in our day constant summer visitants in the circumpolar treeless lands.

We may note, further, that just as there is this evidence to the former occupation of middle and western Europe by an arctic fauna, so we have abundant traces in the same regions of a well-marked arctic flora. High northern species of mosses, the polar willow, the dwarf birch, and various other northern plants have been met with in superficial deposits over a very wide area, extending from southern Sweden and England across middle Europe to the foot of the Alps.

We can not doubt, therefore, that true tundra conditions have formerly prevailed at relatively low latitudes in Europe. The widespread distribution of the arctic animals and plants just mentioned points clearly to that and to no other conclusion. We may therefore reasonably infer that the climate of middle Europe must then have approximated in character to that of northern Siberia, the seasons being doubtless strongly contrasted, and thus compelling annual migrations. With the advent of summer the home of the arctic lemmings was invaded by troops of visitants—by mammoth, woolly rhinoceros, wild horse, saiga, and many others, and by numerous birds. An arctic-alpine vegetation clothed the low grounds, which in the warm season doubtless showed wide stretches of bog and marsh and many shallow lakes. Here and there flourished patches and wider tracts of birch and willow scrub, but the land was practically treeless. Man, we know, was an occupant of middle Europe at this time. Perhaps, like the mammoth and the woolly rhinoceros, he may have been rather a summer visitor than a constant denizen, departing for more clement regions at the approach of winter. We shall probably not err in supposing that the winter would have much resemblance to that now experienced in northern

Siberia—long spells of still weather, with intense frost, interrupted now and again (especially at the changes of the seasons) by fierce snow-storms, in which the wild animals could hardly fail occasionally to perish in large numbers.

How long these tundra conditions obtained we can not tell. All we know is that eventually they gradually passed away and the climate became less arctic. This is shown by the well-ascertained fact that both in the löss and the contemporaneous cave accumulations remains of the arctic animals are confined to the lowest beds, becoming gradually less numerous as we trace them upward, until they finally disappear. But before the last of the tundra forms has vanished remains of a steppe fauna begin to occur. In a word, there was no sudden dying out of one fauna and precipitate appearance of another, but a gradual replacement, consequent, doubtless, upon changing climatic conditions.

All the animals already mentioned as most characteristic of the subarctic steppes are represented in the caves and alluvial deposits of west and middle Europe. Jerboas, pouched marmots, bobacs, and true marmots, tailless hares and others, all formerly flourished in those latitudes. Besides these most characteristic steppe animals occurred many other forms which were not restricted to steppe lands, such as mammoth and woolly rhinoceros, marsh lynx, cave lion, hyena, wolf, common fox, ermine, weasel, badger, reindeer, urus, bison, etc. Many birds also were present—all of them species which in our own day frequent the steppes of southeast Russia. Land shells are also very often found in less or greater abundance along with the relics of the steppe animals just mentioned, most of the shells representing forms that now live in dry steppes, while some are denizens of wooded regions.

The plant remains associated with relics of the steppe fauna are quite in keeping with the latter, but are upon the whole seldom met with, the conditions not being favorable to their preservation. Trunks and branches of trees occur very rarely, the most common remains being a few thin layers and seams of peaty matter, apparently consisting chiefly of grasses. Nevertheless, we need have no doubt that a steppe flora formerly flourished in middle Europe, for (as Engler, Ascherson, Petry, and other botanists have shown) many well-known steppe plants survive in the existing flora of that region.

Among the animals associated with the true steppe forms were some which, as we have seen, had already invaded central Europe in tundra times. Of these, perhaps the most notable are the mammoth and the woolly rhinoceros. Probably they were only summer visitors, but in the subsequent steppe epoch they became truly indigenous and very abundant. The broad valleys and open spaces of central Europe were at that time treeless plains, although woods seem to have existed here and there, especially along the margins of lakes and streams. The climate, we need not doubt, was much like that of the subarctic steppes of southeast Russia and southwest Siberia, regions which, like the tundras, are much exposed to wind action. The general character and distribution of the löss prove its æolian origin, and its organic contents are quite in keeping. We may be sure, then, that dry steppe conditions formerly prevailed throughout central Europe, and that in those regions dust storms and snowstorms must have been of common occurrence. We have seen how, in existing tundras and steppes, the semidomesticated and wild animals of those regions are now and again overwhelmed in storms and smothered in snow. Now, similar catastrophes must have happened again and again in the tundras and steppes of prehistoric times. And we are not left in this matter to mere conjecture, for the carcasses of some of the more notable animals of those days, now extinct, have been preserved to the present in the frozen snows—the famous ice formations of northern Siberia. So perfectly preserved, indeed, was the mammoth discovered by Mr. Adams that its flesh was devoured by wolves and bears, and from the appearances presented by it and others we can not doubt that the animals had perished in snowdrifts. Brandt records, for example, that the congested veins and capillary vessels in the head of a rhinoceros examined by him were charged with coagulated blood, as if the animal had died of suffocation; and Schrenck says of another described by him, that the distended nostrils and gaping mouth were highly suggestive of a similar death. It is probable that these animals were summer visitors to the tundras, overtaken by autumnal snowstorms. If perfectly preserved carcasses are rare, such is not the case with skeletal remains. In many places throughout Siberia the bones of various mammals occur in enormous quantities, huddled together, as it were, in very limited spots. It seems impossible to account for such hecatombs on any other supposition than that they are the silent records of great blizzards and snowtorms. Even in our own time herds of wild reindeer, with their young, are overcome by snowstorms in the tundras, while in North America great flocks of sheep and cattle frequently perish in the same way. Professor Garman, who draws attention to the disastrous results of blizzards in the great prairie lands of that region, is of opinion that the extraordinary heaps of skulls and other remains of the bison that are met with here and there in northern Colorado and Wyoming, are the remains of herds which have been suffocated in snowdrifts.

It is not necessary to suppose that all the relics and remains of the mammoth and its congeners in Siberia are evidence of the destructive effect of blizzards. The animals doubtless met their death under many different circumstances. Sometimes they would appear to have been bogged in swampy holes and morasses. I have referred to the peculiar ice formations of the arctic coast lands. These are sheets of ice of unknown thickness, preserved under more or less thick accumulations of earthy and loamy materials. The ice is believed to represent the blown or drifted snows of prehistoric times, which here and there have been protected from complete dissolution by soil and subsoil flowing over and accumulating upon them, under the influence of thaw, in spring and summer. Such movements of superficial materials are indeed of common occurrence in high latitudes at the present day. The surface of the buried ice strata is very uneven, being furrowed and trenched by deep ruts and hollows. These depressions are filled up with frozen mud, etc., containing vegetable débris and abundant mammalian remains, including those of mammoth and woolly rhinoceros. Probably a large number of the bones may simply have been introduced into the hollows by the flowing soil in spring—they may have been lying originally scattered over the surface. In other cases, however, the animals themselves seem to have fallen or sunk into the depressions. All the evidence leads to the inference that in the warm season these high northern regions were visited abundantly by mammoths, rhinoceroses, horses, bisons, wapiti, and others. Such being the case, it is not hard to understand how the bulkier animals might now and again become trapped in the treacherous bogs and subjacent muds that covered and concealed the ice formations and their deep clefts and depressions.

When we turn to the löss of Europe, we meet with copious evidence to show that the wild animals of our prehistoric steppes and tundras were often done to death in their hundreds and thousands. Again and again great heaps and accumulations of their skulls and skeletal remains have been encountered in our lössic accumulations—appearances exactly recalling the similar bone finds of Siberia and North America. The deposits in which the European bone finds occur are of wind-blown origin, and we seem justified, therefore, in concluding that the animals perished in snowstorms. In these low latitudes, however, we could not expect to meet with ice formations like those of the tundras. But that drifted snows did formerly accumulate in middle Europe, and were preserved for long periods under coverings of sand and other materials, we have good reasons for believing. Indeed, even at the present day the drifted snows in southeast Russia are occasionally buried under sand and so persist for years. In one case recorded by Borszcow, what appeared to be an ordinary sandhill proved to be a mass of congealed snow cloaked in sand about a foot in thickness. Immediately under the surface the snow was granular and névé-like, but a little deeper it was firm and solid like ice. This was in one of the tributary valleys of the Ilek, in the steppes south of Orenburg, about the fiftieth parallel—a relatively dry region. If in a low-lying region so far south snow can be preserved in this way, we may readily believe that in the steppe epoch of middle Europe snowdrifts similarly protected might now and again have persisted for years. But it was during the preceding tundra epoch that this would be most commonly the case. And much interesting evidence is forthcoming to show that in many places thick sheets of congealed snow did accumulate and become buried and preserved at that time. Many of the so-called "rubble drifts" of middle Europe—sheets of rocky rubbish which have traveled down gentle hill slopes and spread themselves over the adjacent low grounds—point to the former presence of great snow drifts, in and upon which the rock débris traveled. These were not glaciers, but simply sheets of névé-like snow, charged with and covered by earthy and rocky débris, which kept moving outward, more especially in spring and summer when the heaps were more or less rapidly melting. The occurrence in this débris of bones of the reindeer and other mammals shows that the deposits belong to prehistoric times. Again, certain phenomena connected with the river gravels of the same period lead to the conviction that the drainage was often interfered with by snowdrifts in tundra times. The river valleys would seem to have become filled in places with alternate sheets of congealed snow or ice and layers of gravel and shingle. Long afterwards, when the interbedded strata of ice melted slowly away, the associated river detritus quietly settled down, and owing to the differential movement of the subsiding materials the longer stones naturally arranged themselves in lines of least resistance, so that now we find them most usually standing on end in the gravel beds.

Thus, apart from the evidence supplied by the bone accumulations of the löss, we have good reason to believe that snowdrifts were of common occurrence in middle Europe in prehistoric times. Doubtless most of the snow which covered the plains of our continent in winter melted and disappeared in summer, just as is the case in the tundras and steppes of our own day. The carcasses of animals that may have perished in blizzards would thus most frequently become uncovered in spring, to be devoured by hyenas, wolves, and bears, and the disarticulated skeletons might often be bleached and weatherworn before they were finally buried in löss. Nor was it only in plains and open valleys that sudden death may have overtaken large numbers of animals at a time. In tundras and steppes alike the wild and semiwild denizens of the plains seek refuge from the drifting snow in the fissures, caves, gullies, and ravines of the hills and mountains, where they are sometimes frozen to death or smothered in snow. Herbivorous and carnivorous animals thus often perish together, for in the presence of a common danger, whether it be prairie or forest fire, or flood or blizzard—natural antipathies and animosities are forgotten, and all alike struggle to escape.

Man, as I have already mentioned, lived in middle Europe in tundra times, and we have abundant evidence of his presence there throughout the succeeding steppe epoch. Again and again his relics and remains have been met with at all levels in the löss throughout central Europe. Thus in the valleys of the Danube and some of its tributaries they have been discovered in undisturbed löss at depths of from 20 to nearly 100 feet from the surface. Not a few of these finds evidently represent old prehistoric camping stations—marked by the presence of quantities of charcoal and ashes, burnt and calcined bones, together with worked flints, bones, and ivory. Among the animal remains are those of mammoth, woolly rhinoceros, musk ox, reindeer, elk, horse, lion, glutton, bear, wolf, arctic fox, common fox, and hyena. Nor is it only in the löss that we have human relics associated with the tundra and steppe faunas. Similar finds have been recorded from many caves and rock shelters, of which we may take the rock shelter of the Schweizersbild, near Schaffhausen, as a good example. The deposits at that place show a clear succession, and tell a highly interesting tale. The following is the sequence, the beds being numbered from below upward:

6. Humus bed.
5. Gray relic bed.
4. Breccia bed, with upper rodent bed.
3. Yellow relic bed.
2. Lemming bed.
1. Gravel bed.

With the lowest bed (No. 1) we need not at present concern ourselves, beyond remarking that it is obviously of fluviatile origin. All the overlying beds are clearly of subaerial formation—the flooded torrential water, which laid down the gravel bed (No. 1), had left the rock shelter high and dry before the succeeding lemming bed began to accumulate. This latter is a yellowish earth, charged with fragments of limestone detached by the weather from the overhanging rock. Scattered through this earth are abundant remains of arctic lemming, arctic fox, mountain hare, reindeer, glutton, and a number of other forms which are constant summer visitors to the tundras. The banded lemming is the most plentifully represented species, and next to it in abundance comes the alpine hare. In close association with this tundra fauna occur flint implements, and awls, chisels, harpoons, and needles of bone and horn. Only one old hearth, with its ashes, was encountered, and from the fact that no calcined bones were met with, while the number of worked bones and antlers was relatively small, it may be inferred that man was not a persistent occupant of the rock shelter during the slow accumulation of the lemming bed. The same conclusion is suggested by the occurrence, especially in the upper part of the bed, of abundant traces of various birds of prey, which appear to have been able to nest undisturbed on the rock and in its crevices.

It can not be doubted, therefore, that during the formation of the lemming bed an arctic climate reigned in north Switzerland. Toward the upper part of that bed, however, we find evidence to show that tundra conditions were gradually passing away. This is indicated by the fact that some of the tundra animals, so common in the lower part of the stratum, become scarcer, and at last cease to appear, while at the same time a few representatives of the subarctic steppe fauna enter upon the scene.

The next succeeding stratum (yellow relic bed) proved to be rich in human relics. It yielded some 14,000 flint implements, and a large number of worked bones and antlers, comprising needles, bodkins and awls, chisels, harpoons, whistles, and other objects. Bits of wood worked and charred, and fragments of worked and unworked lignite were also obtained. Besides these, drawings and patterns were found on reindeer antlers, on bones, and on tablets of limestone, while many shells, fossils, and teeth of the arctic fox and the glutton were met with, bored and pierced, as if they had been used for necklaces and other personal ornaments. The presence throughout this relic bed of nuclei or cores from which flints had been struck, of abundant chips and splinters, of old hearths, ashes, and burnt bones, shows that the reindeer hunters were for a long time constant occupants of the rock shelter.

Turning to the abundant animal remains, we find that these represent no fewer than 49 species, viz, 30 mammals, 15 birds, 3 amphibians, and 1 fish. All the most characteristic tundra forms—the banded lemming and its peculiar associates—are now absent, and in their place we find a true steppe fauna. Amongst the new arrivals are red suslik, pika, and true hamster, and associated with these are such constant visitors of the steppes as manul cat, wild horse, dzeggetai, and various birds. Certain forms which appear in the lemming bed are still represented, as arctic fox, glutton, and others—all of which, however, in our own day range south of the true tundras. Their presence therefore is not out of keeping with the characteristic steppe forms. It is clear therefore that in north Switzerland a tundra fauna was eventually succeeded by a steppe fauna.

Toward the top of the yellow relic bed once more new arrivals begin to put in an appearance, and their presence seems to show that the climate was again gradually changing, for they include red deer, roe deer, wild boar, squirrel, pine marten, and beaver, all of which belong to a forest fauna.

The next stratum in succession is the breccia bed. This consists of small fragments of limestone, either lying loosely together or cemented by calcareous matter. Relics of man were not so common in this bed, although occasional splintered bones and flint implements occurred all through it, and in places were even abundant. About midway between the top and bottom of the breccia occurred a layer of dark-earth, in which human relics and the remains of various rodents were conspicuous. It would seem that during the accumulation of the breccia bed small groups of reindeer hunters only now and again visited the rock shelter; it was evidently not so continually occupied as it had been. The animal remains met with in the stratum undoubtedly tell a tale of changing climatic conditions. Amongst the species represented are reindeer, pika, hare, squirrel-tailed dormouse, garden dormouse, squirrel, water rat, various voles, shrews, mole, ermine, marten, and others. This is obviously a mixed fauna—a few of the steppe animals being still present, but the larger number of the species are forest forms. The fauna of the breccia bed, in a word, marks the transition from steppe to forest conditions. Obviously the climate was gradually improving, the forests continuing to increase at the expense of the earlier steppe flora.

In the gray relic bed that succeeds we lose all trace of the characteristic steppe fauna. The most abundant remains are those of red deer, roe deer, horse, and ox, and with these are associated relics of a number of other forms, such as badger, wild-cat, hare, urus, goat, and sheep. The steppe fauna had now obviously become replaced by a forest fauna. Paleolithic man—the reindeer hunter of the tundras and steppes—had also vanished, and his Neolithic successor now occupied the rock shelter of the Schweizersbild. The gray relic bed and the overlying humus bed tell a most interesting tale, but into that I can not go. It is sufficient to note that the old reindeer hunters seem to have departed before forest conditions had been fully established. We may surmise that as the climate became warmer the reindeer gradually withdrew from the Alpine Vorland. Probably it had already become somewhat scarce during the accumulation of the breccia bed, in which, as will be remembered, traces and remains of it and its hunters become less and less common. One can hardly doubt that the emigration of the reindeer and the final exodus of Paleolithic man from north Switzerland were contemporaneous events, brought about by changing climatic conditions. We can picture to ourselves the old race of hunters, with the contemporaneous steppe fauna, gradually passing east and northeast, while the forests continued to encroach upon and overspread the fertile lands of central Europe. It is possible that Neolithic man may here and there have come into contact with his Paleolithic predecessor, but of this we have no evidence. All we certainly know is that the latter vanished from central Europe with the steppe fauna, and that when Neolithic man made his earliest appearance a forest fauna was in possession of the land.

II.[1]

In my preceding lecture evidence was adduced to show that tundras and steppes, with their characteristic faunas, formerly existed in central and west central Europe. We saw that for a long time the climatic conditions of these regions must have resembled those that now obtain in northern Siberia and the barren grounds of North America, where mosses and lichens form the prevailing growths, and arctic lemmings, hares, and foxes, the reindeer, and the musk ox are the common indigenous animals. All these characteristic species formerly lived in middle Europe. Eventually our tundra flora and fauna gradually disappeared and were as gradually replaced by steppe forms of life. Jerboas, pouched marmots, pika, and many others—such an assemblage as we now see in the subarctic steppes of southeast Russia and southwest Siberia—flourished throughout the regions over

[1] A lecture delivered before the Royal Dublin Society, March 11, 1898.

which the lemmings and their arctic congeners had formerly prevailed. Throughout both tundra and steppe epochs Palæolithic man was an occupant of middle Europe. To the steppe epoch succeeded a forest epoch, with its characteristic fauna, by which time Palæolithic man had vanished, his place being taken by the so-called Neolithic race, or races, for there were several of these.

We must now ask what relation the tundra and steppes deposits bear to other well-known superficial accumulations of Europe. To what particular stage of the geological history of our continent do they belong? When we remember that an arctic-alpine flora formerly flourished on the low grounds of central Europe, it seems extremely probable that the tundra epoch must fall within the glacial period. But the glacial period embraced a complex series of geographical and climatic changes, and it is necessary, therefore, to come somewhat closer to the question. Among the most conspicuous deposits of the Ice age are moraines of all kinds and fluvio-glacial gravels, while the löss, as we have seen, is the most prominent accumulation of the tundra and steppe epochs. How, then, does the latter behave with regard to the typical glacial and fluvio glacial formations? Is it older or younger than these, or are the two sets of accumulations contemporaneous? The answer we get to that question is, at the first blush, disconcerting, for we learn that it is each in turn—sometimes underlying, sometimes overlying, and in other places occurring intercalated among glacial deposits. This only means, however, that löss appears to have been formed during different stages of the Ice age. It will be remembered that while we discussed the wind-blown character of the löss, we left untouched the question of the origin of its materials. Whence were those materials derived which the wind worked over, and largely rearranged, and redistributed in the low grounds of central Europe? To answer this question we must examine more closely the relation borne by the löss to the fluvio-glacial deposits and morainic accumulations. We note, in the first place, that in its horizontal distribution it follows closely that of the valley gravels of glacial times. Where the latter are well developed, the löss appears in full force; where they are wanting there is a like absence of löss. In all the valleys leading down from the Alps to the low grounds of middle Europe the löss puts in a prominent appearance. It obviously bears a close relation to the main lines of drainage, and may be said to be confined to valleys that head in formerly glaciated areas. So, again, in north Germany and southern Russia it spreads over all the low-lying tracts that lay in front of the vast mers de glace of glacial times. These facts alone, taken in connection with the occasional well-stratified character of the löss, the intercalation in it now and again of beds of sand, and the presence ever and anon of fresh-water shells, seem strongly suggestive of a fluviatile origin. And that such was really the origin of the materials of the löss will appear clear enough when we consider the conditions that obtained during a glacial epoch. (See Map A.)

While all northern and northwestern Europe were covered by an ice sheet, the mountains of middle Europe and the alpine lands supported great glaciers, which in many cases deployed upon the low grounds. Vast bodies of water must then have escaped from the terminal front of the northern mer de glace, while the streams and rivers flowing from our mountain tracts must have greatly exceeded their present successors. With each recurring spring and summer wide areas in the low grounds would thus be subject to floods and inundations. Coming from regions where glacial grinding was being carried on upon a most extensive scale, it goes without saying that all these waters would be clouded with the fine flour of rocks. The enormous morainic accumulations formed underneath and in front of the alpine glaciers, and over the vast areas traversed by the Scandinavian mer de glace, bear emphatic testimony to the intensity of glacial erosion. In like manner the great terraces of gravel that stretch down the valleys in front of the alpine moraines and the broad sheets of similar deposits which extend outward from the glaciated tracts of northern Europe, are equally impressive witnesses to the vigor of the flooded glacial rivers. It is certain, however, that gravel, grit, and sand would not be the only materials carried forward by those rivers. As they reached the low-lying tracts their rate of flow would gradually diminish, and finer-grained materials—fine silt and loam—would eventually be deposited. When we consider the great volumes of water descending to the low grounds, we can not, indeed, escape from the conclusion that many wide areas in the plains during a glacial epoch must have been inundated, and in those slack waters and temporary lakes the finer-grained fluvio-glacial sediments would tend to accumulate. We must also bear in view the probability—I had almost said the certainty—of great derangements of the drainage having taken place in middle Europe. In winter, when the rivers of that region were frost bound, snow must frequently have drifted to great depths in the valleys, and the spring and summer thaws would often fail to remove these heaps. In this way the valleys might here and there become entirely filled with the blown and congealed snows of successive years, so as to compel the rivers in summer to rise in flood and to reach levels which they might otherwise have been unable to attain. We have positive proof, indeed, that such accumulations of drift snow actually did appear in extra-glacial regions, for some of them have persisted to the present day. The ice formations of the arctic coast lands, with their associated mammalian remains, certainly belong to the glacial period. They are simply the drifted snows, now converted into granular and massive ice, which accumulated in valleys and depressions outside of the glaciated regions. Protected under a covering of superficial detritus, alluvial matter, and peat, they have in those high latitudes persisted to the present day. Farther south, in central and western Europe, similar masses of congealed snow, as we have seen, appear to have accumulated, and may well have endured for some time after glacial conditions had passed away. In these temperate latitudes, however, they were bound ere long to melt and allow the overlying alluvial deposits to settle down in the manner already described.

There are thus various lines of evidence which lead to the conclusion that during a glacial epoch the lower reaches of all the great valleys opening out from glaciated regions, as well as large tracts of the wide plains extending in front of the northern mer de glace, would be more or less drowned in temporary lakes of turbid water, over the beds of which a fine sediment of somewhat uniform character must have been deposited. And such is generally believed to be the origin of the materials of the löss. The löss, as we now have it, is a fluvio-glacial silt or loam, very largely reassorted and rearranged by the wind. Its history, therefore, is involved with that of the Ice age, and we must consequently turn our attention to the unquestioned deposits of that period, with a view to discover, if we can, at what particular stage of it the glacial silts were worked over by the wind, and tundra and steppe faunas successively occupied the low grounds of middle Europe.

Let us first, then, trace as briefly as may be the history of the glacial and interglacial deposits. Avoiding detail, we shall confine attention to the more salient features of the evidence and try to picture the succession of events from the beginning to the close of glacial times.

The facts upon which geologists base their conclusion that a vast ice sheet formerly covered much of northern and northwestern Europe, while great snow fields and glaciers existed not only in the Alps, but in many of the minor mountain ranges of central and even of southern Europe, may be very briefly summed up.

First, we have the evidence supplied by morainic accumulations of all kinds—bottom moraines or bowlder clays and terminal moraines. Second, we have the proofs of former glaciation afforded by striated rocks and roches moutonnées and by the crushed, broken, tumbled, and confused rock surfaces that occur so frequently underneath the bottom or ground moraines. Third, we have the presence of certain remarkable ridges of gravel and sand which appear to have been formed in tunnels under the ice, and of enormous sheets of similar materials which have been spread out by the waters escaping from the terminal front of the inland ice of northern Europe, while in all the great valleys leading down from the Alps and other glaciated mountains we see broad terraces of alluvial detritus which have been deposited by torrential streams and rivers. All those fluvio-glacial deposits, when followed from the low grounds into the regions occupied by moraines, are found to dovetail with the latter and are consequentl- of contemporaneous origin.

By mapping rock striæ and noting the general trend of the erratics which constitute so large a portion of the ground moraines we acquire a knowledge of the directions followed by the inland ice and the great glaciers. Not only so, but by tracing the horizontal and vertical distribution of glacial phenomena we have been able to show what regions were wholly ice covered, to measure the thickness attained by ice sheets and glaciers, and to estimate the angle of their surface slope. It is, in short, quite possible now to draw maps of Europe which shall give a fairly accurate presentment of the aspect presented by our continent in glacial times. On maps of a sufficiently large scale we can delineate not only the great inland ice of the north and northwest, but the snow fields and numerous glaciers of the Alps and other mountainous tracts, together with the areas covered by fluvio-glacial deposits.

So much for what we may call the physical evidence. But this is not all, for associated with the true glacial accumulations occur in many places beds charged with the remains of arctic-alpine plants and animals. The evidence of fossil-organic remains, therefore, fully supports the conclusions arrived at from a study of purely glacial phenomena. We know that arctic forms of life lived in our seas at the time of which I am speaking, and that the countries outside of the glaciated areas were then clothed and peopled by an arctic-alpine flora and fauna.

But, as if in contradiction of this evidence, certain other deposits charged with the remains of temperate and southern species of plants and animals appear intercalated among the true glacial accumulations. The study of these and of their relation to subjacent and overlying morainic and fluvio-glacial accumulations has led to the conclusion that the Glacial period was not one continuous period of arctic conditions, but a cycle or succession of alternating cold and genial epochs.

So far as we at present know, glacial conditions first supervened in late Tertiary times—in the so-called Pliocene period. In the earlier part of that period the European climate had been singularly genial. Warm seas, tenanted by many southern species of mollusks, washed the shores of the British area, while the land was clothed with a much more varied and abundant flora than we now possess. Great forests seem to have covered vast areas, occupying not only the plains and the river valleys, but extending far up the mountain slopes of such regions as France without much change of character. The same species, indeed, appear to have flourished equally well in Cantal and central Italy. Some of these had come down from early Tertiary times and were destined soon to become extinct; some, again, were special forms belonging to genera which in our day are exotic; others were species which have survived to the present in more southern and eastern regions, while yet others are still represented in Europe by identical or very closely allied species. Thus the flora of the Pliocene was connected both with the past and the present plant life of Europe, while at the same time it had relations with the floras of distant southern and eastern regions—with Florida, the Canary Islands, China, and Japan. All the evidence thus implies for early Pliocene times an equable and uniform climate, which permitted the intimate association in our continent of many plants which are now no longer able to exist at similar elevations or in one and the same latitude.

The mammalian life of Europe in early Pliocene times was in keeping with the flora. The deinotherium and mastodon still survived, and along with these were rhinoceroses, hippopotamuses, and elephants, and many cervine and bovine animals. Carnivores of extinct and still existing types and many monkeys were also present.

Such, then, was the character of the climate, and the aspect of the flora and fauna of Europe in preglacial times. The gradual approach of glacial conditions is evidenced by the fact that the percentage of northern and arctic shells in the upper Pliocene marine deposits increases from the lower to the higher members of the series. We note a gradual dying out of southern species and a gradual coming in of northern forms, until at last the beds are charged with the remains of a truly arctic marine fauna. We have no direct evidence as to the terrestrial conditions which obtained in Britain and Ireland at that time. The climate, however, could not have been genial and temperate as it is now. The presence of an arctic fauna in our seas shows that our shores were washed by currents coming from the north, and not as at present from the southwest. Reasoning from the analogy of to-day, therefore, we might infer that the climate of our area was probably not unlike that of Labrador.

The traces of the first glacial epoch are more clearly read in the deposits of the continent. An immense glacier at this time, fed from the uplands of Scandinavia, filled the basin of the Baltic. The bottom moraine of that great ice flow is seen in the low grounds of Scania, in southern Sweden, while its fluvio-glacial deposits have been detected at many places in north Germany. The alpine lands were contemporaneously covered with extensive snow fields, and large glaciers descended the deep mountain valleys, to deploy upon the Vorländer, in Switzerland, and south Germany. The terminal moraines of these glaciers have been mapped out, and the general conditions of the epoch have been so well ascertained that the position of the snow line at the time has been determined. It is believed to have been upon an average some 4,000 feet lower than now. While the valleys of the Alps were thus gorged with ice and the basin of the Baltic was occupied by an immense mer de glace, it is not probable that the higher parts of our islands could have escaped glaciation. We can hardly doubt that snow fields and glaciers must also have existed here. No trace of these, however, has been or is ever likely to be detected. Direct evidence of the kind, if it ever did obtain, has been obscured or destroyed by the action of the much greater glaciers and ice flows of later epochs.

In tracing the succeeding events in the geological history of Europe, I shall confine attention in the first place to the alpine lands, for it is in the low grounds at the base of those mountains that the relation of the löss to the glacial and fluvio-glacial deposits can be most clearly made out.

It has now been ascertained that glaciers have on three successive occasions filled the great mountain valleys of the Alps and descended to the low grounds. The earliest advance I have already described—this constitutes the first glacial epoch of Swiss geologists. It was followed by a long spell of genial conditions when the great glaciers melted away, and retired to the inner recesses of the mountains. Many relics of the flora of this genial epoch have been preserved. Thus in the valley of the Inn, near Innsbruck, certain deposits have yielded an assemblage of plants similar to that which we now meet with in the valleys of the mountain regions south of the Black Sea—most of the plants being existing species. The mean annual temperature of the regions in which that flora now flourishes is 57° to 65° F., while that of Innsbruck at present is only 47°. But in the genial epoch of which I speak, the flora in question flourished on the mountain slopes overlooking Innsbruck at elevations of 3,600 to 3,900 feet, where the mean annual temperature in our day does not exceed 40°. This is enough to show us that the climatic conditions of the alpine valleys must formerly have been considerably more genial than at present. From this and similar evidence in other alpine valleys we may safely infer that the retreat of the glaciers was the result of a great change of climate, and that during the first interglacial epoch the snow fields and glaciers must have retired to the highest ridges of the mountains.

The plant beds just referred to are not only underlaid, but overlaid by bottom or ground moraines, the overlying moraines belonging to the second glacial epoch. It was during this epoch that the glaciers of the Alps attained their greatest development—the snow line becoming depressed to 4,700 feet below its present level. The glaciers now pushed their way into the low grounds considerably beyond the limits reached by their predecessors in the first glacial epoch. That the second, like the first glacial epoch, was of long duration is shown by the amount of erosion effected by the ice flows and the enormous extent of their bottom and terminal moraines.

Overlying the ground moraines of that epoch we again come upon alluvial deposits in many places, which are crowded with the remains of a temperate flora—a flora resembling that of the low grounds of Switzerland and north Italy in our own days. It is obvious, therefore, that when such a flora flourished in the great valleys of the Alps the climate could not have been less genial than the present; the snow line must have again retreated to a higher level, and the névés and glaciers were probably not more extensive than they are now. This constitutes the second interglacial epoch of Swiss geologists. Ere long it was followed by a third general advance of the glaciers, which once more reached the low grounds at the base of the Alps, but did not flow so far as their predecessors of the preceding or second glacial epoch. The snow line of this third glacial epoch stood at an average level of about 4,400 feet below the present.

Each glacial epoch was necessarily marked by profound glacial erosion, and the consequent formation of massive sheets of ground moraine in the lower reaches of the great valleys, and of huge terminal moraines at or opposite their mouths. Enormous quantities of shingle and gravel were at the same time swept outward by the rivers escaping from the ice—each series of terminal moraines being thus closely associated with its separate and distinct set of fluviatile deposits. No difficulty is found in separating those successive accumulations of gravel. They form terraces lying one within the other at three successive levels. The highest rises upon an average 250 to 300 feet above the present rivers; the surface of the middle terrace is about 100 feet below the surface of the highest, and about the same distance above the level of the lowest terrace. Each terrace rests upon solid rock, and it is obvious, therefore, that the several epochs of gravel accumulation have been separated by epochs of active river erosion. This remarkable valley-within-valley formation is clearly the result of climatic changes. The highest terrace indicates the action of flooded rivers escaping from the glaciers of the first glacial epoch. These glaciers then disappeared or shrank into comparative insignificance, and an interglacial epoch of active valley erosion succeeded—the rivers cutting their way down for a hundred feet or more into the solid rocks. Next came the second glacial epoch, and the lowered valley bottom was again deeply covered with gravel. The glaciers of this stage then in their turn retired, and a second interglacial epoch supervened, when the rivers as before deepened their channels, working down through the older gravels and excavating the underlying rocks. Thereafter the third glacial epoch ensued, and a new series of gravels was deposited at a lower level than the preceding accumulation. Lastly, this third glacial epoch passed away and the rivers again trenched the fluvio-glacial gravels, the upper surface of which is now much above the reach of the greatest floods.

What relation, then, does the löss bear to the glacial and interglacial accumulations of the alpine lands? Fortunately to this question a definite reply can be given. It is dovetailed with the glacial deposits in such a manner as to show that its formation has taken place at successive epochs. Thus it occurs occupying an interglacial position between the accumulations of the first and second, and between those of the second and third glacial epochs. When we pass down the valley of the Rhine a similar succession is encountered. In the wide plain lying between the Vosges and the Black Forest, löss is met with on the same geological horizons, overlying the gravel terraces of the first and the second glacial epochs. Not only so, but even the youngest or lowest gravel terrace (that of the third glacial epoch) is in like manner sheeted in löss. The löss on these three separate horizons is for the most part wind blown, and exactly resembles that of middle Europe generally, showing the same structure and arrangement, and containing a similar assemblage of organic remains.

To what extent each of these "horizons" of löss may be represented in the low grounds of middle Europe we can not definitely say. But as the materials of the löss are for the most part of fluvio-glacial origin, it is obvious that such accumulations must have been formed during each successive advance of the alpine glaciers. As each glacial epoch passed away those accumulations were greatly modified by the wind, and drifted into the valleys that drain the Alps, where they were subsequently covered and to some extent preserved under the morainic and fluvio-glacial deposits of the succeeding epoch of glacial advance. It seems probable, therefore, that the wind-blown löss of the low grounds of middle Europe does not belong exclusively to any one particular stage of the glacial period. It is impossible, however, at present to divide it up into separate stages. But we may feel sure that if tundra and steppe faunas succeeded each other again and again in the valley of the Rhine, they could hardly fail to have done the same in the wide plains of middle Europe.

It will be remembered that at the Schweizersbild the deposits containing remains of tundra and steppe faunas rest immediately upon fluvio-glacial gravels. These gravels were laid down during the third glacial epoch. It is quite certain, therefore, that the faunas referred to must have entered Switzerland after the retreat of the glaciers from the low grounds. But how long an interval may have elapsed between the disappearance of the glaciers and the advent of the lemmings and their congeners we can not tell. All we know is that after the appearance of the tundra fauna in Switzerland the climate, at first cold and arctic, gradually became less extreme, so that in time a steppe fauna, and afterwards a forest fauna, succeeded. In other words, no perceptible hiatus separates the present from the conditions that obtained when the reindeer hunter vanished from the alpine lands. He was succeeded by Neolithic man, just as the latter was followed by the men who used bronze and iron implements and tools. So far as the evidence of the Schweizersbild rock shelter is concerned, we should infer that no great alternations of cold and genial epochs followed after the final retreat of the great glaciers of the third glacial epoch. But, as we shall see presently, the tale told by that interesting rock shelter is incomplete. Certain considerable climatic changes did take place after the third glacial epoch had passed away. The evidence of such change, however, though not wanting in the alpine lands, is much more clearly displayed in northwestern Europe. To the testimony yielded by the glacial and interglacial deposits of that region, therefore, we shall now direct attention.

It will be remembered that during the first glacial epoch a great Baltic glacier existed, and an arctic fauna lived in the North Sea. That epoch was succeeded by the first interglacial stage, when the southern part of the North Sea became dry land, and England was occupied by an abundant mammalian fauna—comprising hippopotamus, elephants, rhinoceros, horse, bison, boar, many kinds of deer, and a number of carnivores, including bears, hyena, saber-toothed tiger, wolf, fox, etc. The contemporaneous flora was temperate, resembling very much that which now exists in southeast England. In similar latitudes on the continent the same mammalian fauna flourished, while the flora was temperate, but suggestive of less strongly contrasted summers and winters than the present. A kind of insular climate, in short, seems to have characterized north Germany.

To this genial interglacial epoch succeeded the second and most extreme of all the glacial epochs. An enormous mer de glace then extended over all northern and northwestern Europe, from the British area in the west to the Urals in the east, and from Lapland in the north to the mountains of middle Europe in the south. (See Map B.)

When these extreme conditions eventually passed away, the second interglacial epoch supervened, characterised, as the earlier one had been, by a genial temperate climate, by the presence in England and the continent of the great pachyderms and their congeners, and by the appearance of Paleolithic man.

This second interglacial epoch was in its turn succeeded by a third advance of the Scandinavian "inland ice," which once more coalesced with the mer de glace of the British area. It did not, however, flow so far as its predecessor. Nevertheless, it reached the Valdai Hills in the east, the valley of the Elbe in the south, and covered all Scotland, the north of England, and the major portion of Ireland. This ice flow was most probably contemporaneous with the third advance of the great glaciers of the Alps. (See Map C.)

It is noteworthy that the löss in north Germany nowhere overlies the morainic accumulations of the third glacial epoch. It does, however, cover the marginal area of the ground formerly invaded by the second and greatest mer de glace. This clearly shows that the löss of north Germany must belong, in part at least, to the second interglacial epoch. The fact that it everywhere avoids the regions over which the third great ice sheet prevailed, does not, however, prove that tundra and steppe conditions did not supervene at a later date in middle Europe. The evidence supplied by the alpine lands, and the great valleys that drain those lands, is quite conclusive of the contrary. There is no doubt whatever that the Paleolithic reindeer hunters followed the chase in middle Europe long after the third great Scandinavian mer de glace had retired from the plains of north Germany. The geographical distribution of the wind-blown löss shows that steppe conditions were restricted to a broad belt of land in middle Europe.

These conditions were rendered possible by the former greater extension of our continent into the Atlantic, when the major portion of the North Sea and the English Channel were dry land, and the British Islands formed part of the continental area.

Considerable climatic changes continued to take place after the passing of the third glacial epoch. These have left their traces in the alpine lands, but they are nowhere so clearly seen as in northern and northwestern Europe. Temperate conditions supervened in north Germany, the flora and fauna closely resembling those of the present. But eventually a relapse to glacial conditions followed, and from the Scandinavian snow fields another invasion of north Germany took place. Norway, Sweden, and Finland were now once more shrouded in ice, and a great Baltic glacier came into existence, the gigantic terminal moraines of which are met with in Denmark, Schleswig-Holstein, and Prussia. The Scottish Highlands and other mountainous parts of the British Islands at the same time nourished local ice sheets and large valley glaciers, which in many cases descended to the sea. The alpine lands in like manner witnessed a recrudescence of glaciation, large glaciers flowing into the great longitudinal valleys, but nowhere deploying as before upon the low grounds. It is to this stage, probably, that we should assign the tundra fauna of the Schweizersbild. (See Map D.)

The succession in that interesting rock shelter has shown that as the severity of the climate relaxed, steppe and forest faunas successively followed the disappearance of the tundra forms. The climate of Europe generally became temperate, and immense forests overspread wide regions. It was during the approach of these conditions, as we have seen, that Paleolithic man seems finally to have vanished and the Neolithic races to have made their earliest appearance in Europe. The British Islands at this time formed part of the continent and the Baltic existed as a great fresh-water lake. The lower buried forests of our peat bogs are among the conspicuous remains of this stage. Eventually, however, submergence ensued, the British Islands were severed from the continent, and the sea again invaded the Baltic basin. It is notable that the character of the marine fauna which at this stage lived off the coasts of Scandinavia and Britain is indicative of more genial conditions than now obtain. The climate, however, gradually became colder, the vertical and horizontal range of the forests was restricted, and snow fields again appeared among the higher mountains of our islands. In Scotland glaciers here and there came down to the sea, and dropped their moraines upon the beaches then forming; the large majority, however, terminated inland. At that time the snow line in north Britain ranged between 2,000 and 2,600 feet. Similarly, in Norway and in the Alps an advance of glaciers took place—the snow line in southern Norway being about 2,400 feet, while in the alpine lands it seems to have averaged 7,500 feet, or some 1,600 feet lower than the present.

Later climatic oscillations followed, but on a decidedly reduced scale. The effect of these was, naturally enough, most marked in northwestern Europe, decreasing gradually southward, and doubtless eventually fading away in the lower latitudes of the continent. It is not necessary for my present purpose to do more than briefly indicate the general character of these later changes so far as they affected our own area.

The local glaciers of the British mountains, some of which, as I have said, actually entered the sea, at last began to retreat. The climate became more genial, and so once more favored the growth of forests, which in many places began to overspread the now dry peat bogs, beneath which the trees of the earlier forest epoch lay entombed. Eventually, however, colder and more humid conditions returned, and small glaciers appeared in a few places among the loftiest heights of the Scottish Highlands. The position of the moraines of these glaciers indicates a height of 3,500 feet for the snow line. The forests now, as before, began to decay in many places, and the bog moss and its allies again extended in all directions, and so, eventually, a second forest bed became entombed in growing peat. It is needless to say that the evidence of these later changes is not restricted to Scotland. The bogs of the two sister countries, and of the corresponding latitudes on the continent, present us with precisely the same phenomena.

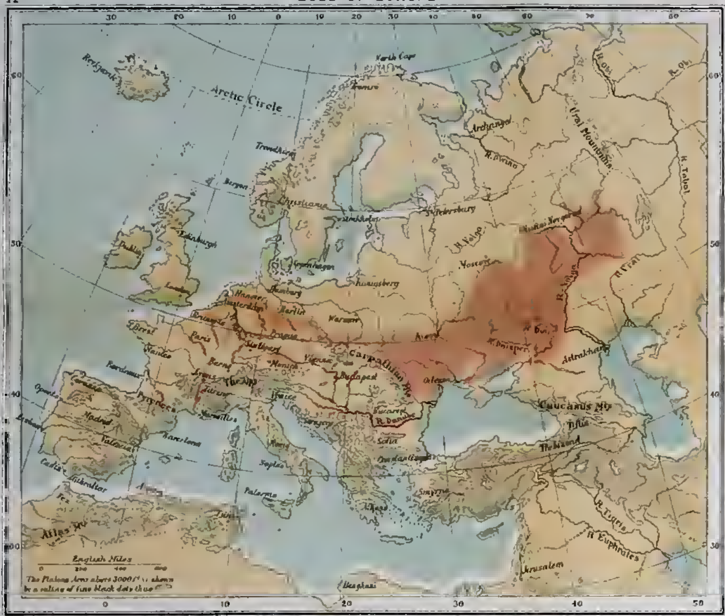
The present decayed aspect of the bogs in many places where they formerly flourished, and the fact that certain plants and groups of plants are once more beginning to invade such wastes, shows that we are now living under somewhat milder and less humid conditions.

Although these later climatic oscillations certainly affected the distribution of plants and animals to some extent in northern and northwestern Europe, yet the changes brought about were insignificant as compared with those which characterized the alternations of preceding glacial and interglacial epochs. The earlier cold and genial stages were strongly contrasted, and marked by great migrations of flora and fauna. But, as the strange cycle drew to a close, the contrast between glacial and interglacial phases became less and less pronounced and gradually faded away into the present. The steppe fauna vanished from middle Europe during the fourth interglacial epoch, and it never returned. The climatic oscillations that followed were on too small a scale to induce great migrations, and thus the succeeding forest fauna retained its place. Hence in such a section as that seen in the rock shelter of Schweizersbild, we find no recognizable evidence of the climatic changes to which the buried forests and peat bogs and the small local moraines of northern and northwestern Europe bear testimony. It is thus only by correlating and comparing the evidence over the widest area that we are able to get the story completed.

In fine, we have seen that tundras and steppes appeared at successive epochs in prehistoric Europe. The former were contemporaneous with the great ice sheets and glaciers, while the later came into existence when glacial conditions were passing away. The tundra and steppe conditions of our continent belong, in short, to that remarkable cycle of climatic and geographical changes known as the Ice age or glacial period. Paleolithic man undoubtedly lived through both phases, for his relics and remains are found associated alike with the arctic lemmings and the succeeding steppe animals. Whether the reindeer hunter of middle Europe ever came into contact there with the Neolithic man we can not tell. Were we to trust to negative evidence we should say he never did. But negative evidence can not be trusted. It is quite possible that the two races may have met and even commingled, but of this no proof is forthcoming. The strong hiatus that separates the Old Stone and the New Stone epochs in western and northwestern Europe has not yet been bridged over in middle and southern Europe. When last we see Paleolithic man he is hunting the reindeer and the mammoth in the Danubian steppes. His Neolithic successor seems not to have appeared in middle Europe before steppe conditions had passed away and a forest flora and fauna had become dominant.

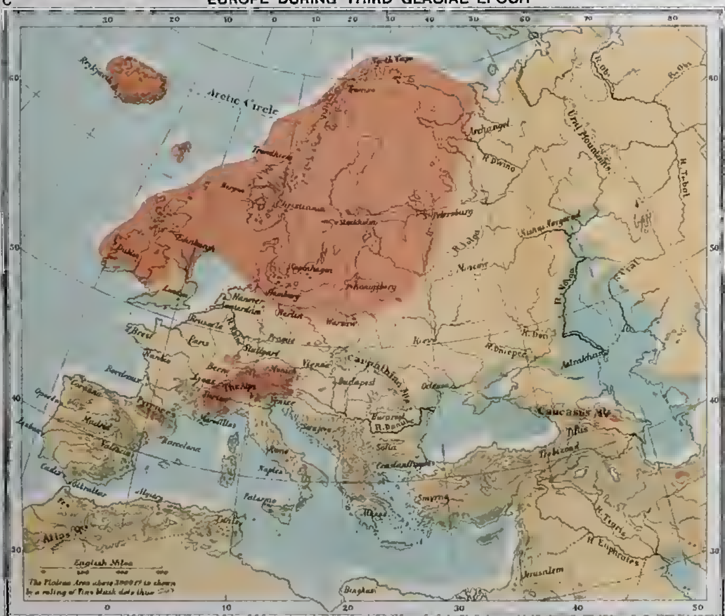
A. Hoen & Co. Lith. Baltimore

A
LOSS OF EUROPE



B
MAXIMUM GLACIATION OF EUROPE (Second Glacial Epoch)

C
EUROPE DURING THIRD GLACIAL EPOCH



D
EUROPE DURING FOURTH GLACIAL EPOCH

THE TUNDRAS AND STEPPES OF PREHISTORIC EUROPE

(REPRODUCED FROM SCOTTISH GEOGRAPHICAL MAGAZINE)

MODIFICATION OF THE GREAT LAKES BY EARTH MOVEMENT.[1]

By G. K. Gilbert,

United States Geological Survey.

The history of the Great Lakes practically begins with the melting of the Pleistocene ice sheet. They may have existed before the invasion of the ice, but if so their drainage system is unknown. The ice came from the north and northeast, and spreading over the whole Laurentian basin invaded the drainage districts of the Mississippi, Ohio, Susquehanna, and Hudson. During its wandering there was a long period when the waters were ponded between the ice front and the uplands south of the Laurentian basin, forming a series of glacial lakes whose outlets were southward through various low passes. A great stream from the Erie Basin crossed the divide at Fort Wayne to the Wabash River. A river of the magnitude of the Niagara afterwards flowed from the Michigan Basin across the divide at Chicago to the Illinois River; and still later the chief outlet was from the Ontario Basin across the divide at Rome to the Mohawk Valley.

The positions of the glacial lakes are also marked by shore lines, consisting of terraces, cliffs, and ridges, the strands and spits formed by their waves. Several of these shore lines have been traced for hundreds of miles, and wherever they are thoroughly studied it is found that they no longer lie level, but have gentle slopes toward the south and southwest. Formed at the edges of water surfaces, they must originally have been level, and their present lack of horizontality is due to unequal uplift of the land. The region has been tilted toward the south-southwest. The different shore lines are not strictly parallel, and their gradients vary from place to place, ranging from a few inches to 3 or 4 feet to the mile.

The epoch of glacial lakes, or lakes partly bounded by ice, ended with the disappearance of the ice field, and there remained only lakes of the modern type, wholly surrounded by land. These were formed one at a time, and the first to appear was in the Erie Basin. It was

[1] Reprinted from the National Geographic Magazine, Vol. VIII, No. 9, September, 1897. A more extended paper of similar scope entitled "Recent earth movement in the Great Lakes region," was printed in the Eighteenth Annual Report of the United States Geological Survey, Part II, pp. 595–617.

much smaller than the modern lake, because the basin was then comparatively low at the northeast. Its outline is approximately shown by the inner dotted line of the accompanying map. Instead of reaching from the site of Buffalo to the site of Toledo, it extended only to a

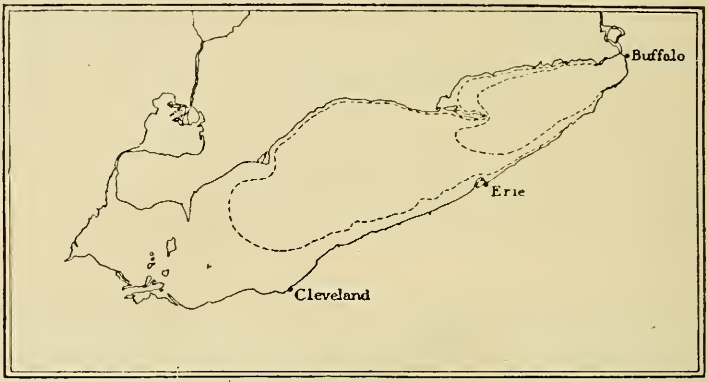


Fig. 1.

ANCIENT AND MODERN OUTLINES OF LAKE ERIE.

The broken lines show the positions of the shores at two epochs of the lake's history.

point opposite the present city of Erie, and it was but one-sixth as large as the modern lake. Since that time the land has gradually risen at the north, canting the basin toward the south, and the lake has gradually encroached upon the lowlands of its valley. At a date to

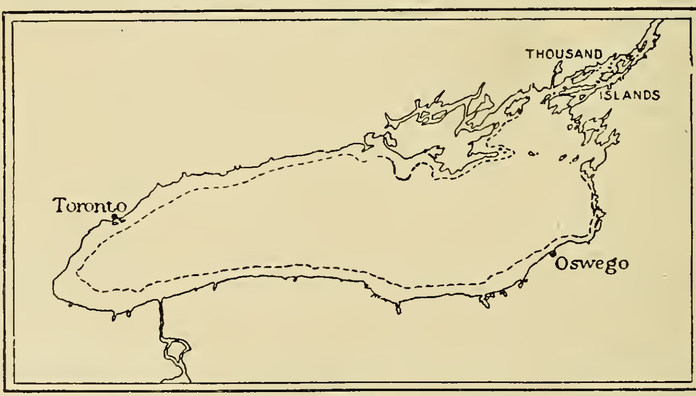


Fig. 2.

ANCIENT AND MODERN OUTLINES OF LAKE ONTARIO.

The broken line shows the original extent of the lake.

be presently mentioned as the Nipissing, the western end of the lake was opposite the site of Cleveland, as indicated by another dotted line.

The next great lake to be released from the domination of the ice was probably Ontario, though the order of precedence is here not equally clear. Before the Ontario Valley held a land-bound lake it was occupied by a gulf of the ocean. Owing to the different attitude of the land, the water surface of this gulf was not parallel to the present lake surface but inclined at an angle. In the extreme northeast, in the vicinity of the Thousand Islands, the marine shores are nearly 200 feet above the present water level, but they descend southward and westward, passing beneath the lake level near Oswego, and toward the western end of the lake must be submerged several hundred feet. This condition was of short duration, and the rising land soon divided the waters, establishing Lake Ontario as an independent water body. The same peculiarity of land attitude which made

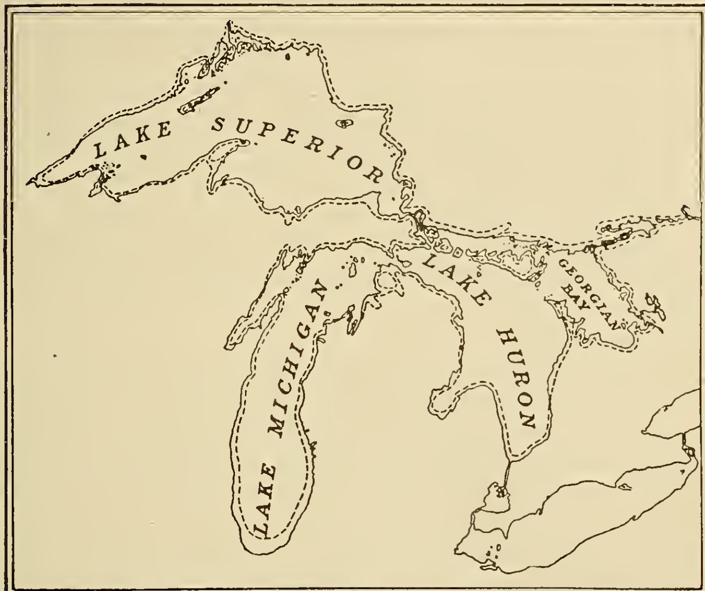


Fig. 3.

THE NIPISSING GREAT LAKE (AFTER TAYLOR).

Its boundaries are shown by the broken line.

the original Erie a small lake served to limit the extent of Ontario, but the restriction was less in amount because of the steeper slopes of the Ontario basin. Here again the southward tilting of the land had the effect of lifting the point of outlet and enlarging the expanse of the lake.

There is some reason to think that the upper lakes—Huron, Michigan, and Superior—were at first open to the sea, so as to constitute a gulf, but the evidence is not so full as could be desired. When the normal lacustrine condition was established they were at first a single lake instead of three, and the outlet, instead of being southward from Lake Huron, was northeastward from Georgian Bay, the outlet river following the valleys of the Mattawa and Ottawa to the St. Lawrence. The triple lake is known to us chiefly through the labors of F. B. Taylor, who has made extensive studies of its shore line. This line, called the Nipissing shore line, is not wholly submerged, like the old shores of Lakes Erie and Ontario, but lies chiefly above the present water surfaces. It has been recognized at many points about Lake Superior and the northern parts of Lakes Huron and Michigan, and measurements of its height shows that its plane has a remarkably uniform dip, at 7 inches per mile, in a south-southwest direction, or, more exactly, S. 27° W. As will be seen by the accompanying map, reproduced from Taylor, it crosses the modern shore line of Lake Superior near its western end, thereby passing beneath the water surface, and it similarly passes below the surface of Lake Michigan near Green Bay and below the surface of Lake Huron just north of Saginaw Bay. The southward tilting of the land, involving the uplift of the point of outlet, increased the capacity of the basin and the volume of the lake, gradually carrying the coast line southward in Lake Huron and Lake Michigan, until finally it reached the low pass at Port Huron and the water overflowed via the St. Clair and Detroit channels to Lake Erie. The outlet by way of the Ottawa was then abandoned, and a continuance of the uplift caused the water to slowly recede from its northern shores. This change after a time separated Lake Superior from the other lakes, bringing the St. Marys River into existence, and eventually the present condition was reached.

These various changes are so intimately related to the history of the Niagara River that the Niagara time estimates, based on the erosion of the gorge by the cataract, can be applied to them. Lake Erie has existed approximately as long as the Niagara River, and its age should probably be reckoned in tens of thousands or hundreds of thousands of years. Lake Ontario is much younger. All that can be said of the beginning of Great Lake Nipissing is that it came long after the beginning of Lake Erie, but the date of its ending, through the transfer of outlet from the Mattawa to the St. Clair, is more definitely known. That event is estimated by Taylor to have occurred between five thousand and ten thousand years ago.[1]

The lake history thus briefly sketched is characterized by a progressive change in the attitude of the land, the northern and northeastern portions of the region becoming higher, so as to turn the waters more and more toward the southwest. The latest change, from Great Lake Nipissing to Great Lakes Superior, Michigan, and Huron, involving an uplift at the north of more than 100 feet, has taken place within so short a period that we are naturally led to inquire whether it has yet ceased. Is it not probable that the land is still rising at the north and the lakes are still encroaching on their southern shores? J. W. Spencer, who has been an active explorer of the shore lines of

[1] Studies in Indiana Geography, X. A short history of the Great Lakes. Terre Haute, 1897.

the glacial lakes and has given much study to related problems, is of opinion that the movements are not complete, and predicts that they will result in the restoration of the Chicago outlet of Lake Michigan and the drying of Niagara.[1]

The importance of testing this question by actual measurements was impressed upon me several years ago, and I endeavored to secure the institution of an elaborate set of observations to that end. Failing in this, I undertook a less expensive investigation, which began with the examination of existing records of lake height as recorded by gage readings, and was continued by the establishment of a number of gage stations in 1896. To understand fully the nature of this investigation it is necessary to consider the difficulties that arise from the multifarious motions to which the lake water is subject.

If the volume of a lake were invariable, and if its water were in perfect equilibrium under gravity, its surface would be constant and level, and any variation due to changes in the height of the land could be directly determined by observations on the position of the water surface with reference to the land; but these conditions are never realized in the case of the Great Lakes, where the volume continually changes and the water is always in motion. The investigator therefore has to arrange his measurements so as to eliminate the effect of such changes.

Consider first the influence of wind. The friction of the wind on the water produces waves. These are temporary and practically cease in periods of calm; the perpetual ground swell of the ocean is not known on the lakes. The friction of the wind on the water also drives the water forward, producing currents. The water thus driven against the lee shores returns in undercurrents, but the internal friction of the water resists and delays the return, and there is consequently a heaping of water against lee shores and a corresponding lowering of its level on other shores. During great storms these differences amount to several feet, reaching a maximum in Lake Erie; in October, 1886, a westerly gale is reported to have raised the water 8 feet at Buffalo and depressed it 8 feet at Toledo.[2] For light winds the changes of level are much smaller, but they are nevertheless appreciable, and they have even been detected in the case of the gentle "land and sea" breezes which in calm weather are created by the diurnal cycle of temperature change on land.

The water is also sensitive to atmospheric pressure. If the air pressed equally on all parts of the lake surface, the equilibrium of the water would not be disturbed; but its pressure is never uniform. As shown by the isobars on the daily weather map, there are notable differences of pressure from point to point, and within the length of one of the Great Lakes these often amount to several tenths of a barometric inch.

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[1] Proc. Am. Ass. Adv. Sci., Vol. LIII, 1894, p. 246.

[2] Science, Vol. VIII, pp. 34, 391. The effect of a storm in October, 1893, is ably discussed by William T. Blount, in Ann. Rept. Chief of Engineers, U. S. A., for 1894, part 6, pp. 3431–3435.

A column of mercury 0.1 inch high weighs as much as a column of water 1.3 inches high; and whenever the atmospheric pressure at one point on a lake exceeds the pressure at another point by the tenth of a barometric inch, the water level at the first point is, in consequence, 1.3 inches lower than the water level at the second point. When a cumulus cloud forms over the water, there is a reaction on the water, disturbing its equilibrium, and the passage of a thunderstorm often produces oscillations attracting the attention of even the casual observer. Such sudden and temporary variations of pressure give rise to waves analogous to those caused by a falling pebble, except that they are broad and low, and these waves not only travel to all parts of a lake, but are continued by reflection, so that a local storm at one point is felt in the water surface at all points and for a considerable period. The passage of the great atmospheric waves associated with ordinary cyclonic storms and the impulses given by winds are also able to set the whole body of the lake in motion, so that it sways from side to side or end to end like the swaying water in a tub or basin, and these swaying motions are of indefinite continuance. In the deeper lakes, and probably in all the lakes, they are so enduring as to bridge over the intervals from impulse to impulse. Such oscillations, which appear at any point on the coast as alternate risings and fallings of the water, with periods ranging from a few minutes to several hours, are called seiches. Their amplitude is usually a few inches, but at the ends of lakes is sometimes a foot or more.

The lakes, like the ocean, are swayed by the attractions of the sun and moon. Their tides are much smaller than those of the ocean, and are even small as compared to the seiches, but they are still measurable. At Milwaukee the lunar tide rises and falls more than an inch and the solar tide a half inch. At Chicago and Duluth each tide amounts to an inch and a half, and their combination at new and full moon to 3 inches.

Water is continually added to each lake by rivers and creeks, but the rate is not uniform. Usually a few freshets, occurring within two or three weeks, contribute more water than comes during all the remainder of the year. Water is also added in an irregular way by rain and snow falling directly on the lake. It is subtracted by evaporation, the rate of which varies greatly, and by overflow, which varies within moderate limits. The volume of water contained in the lake, being subject to these variable gains and losses, is itself inconstant, and the general height of the water surface therefore oscillates. In average years the range of variation for Lake Superior is 12 inches; for Lakes Michigan and Huron, 12 inches; for Lake Erie, 14 inches, and for Lake Ontario, 17 inches. Low water occurs normally in January or February for all the lakes except Superior, where it occurs in March. High water is reached sooner in the lower lakes, June being the usual month for Ontario, June or July for Erie, July for Michigan and Huron, and August or September for Superior. Figure 4 shows the character of the annual oscillations, as given by averages of long series of years.

In a wet year more water enters the lake than leaves it, and there is a net rise of the surface; in a dry year there is a net fall. A series of wet years produce exceptionally high water and a series of dry years exceptionally low, so that the entire range of water height is considerably greater than the annual range. The recorded range for Lakes Superior, Michigan, and Huron is between 5 and 6 feet; for Erie and Ontario, between 4 and 5 feet.

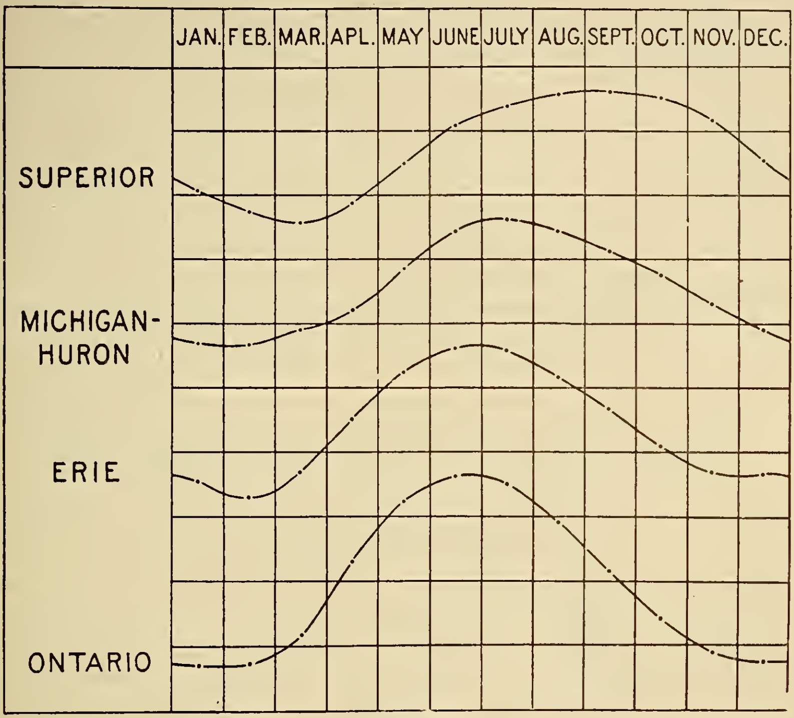

Fig. 4.

ANNUAL OSCILLATIONS OF THE SURFACES OF THE LAURENTIAN LAKES.

Compiled from monthly means published by the Chief of Engineers, U. S. A. Each vertical space represents 6 inches. The observations for Lake Superior cover the period 1862–1895; for Michigan-Huron, 1860–1895; for Erie, 1855–1895; for Ontario, 1860–1895.

The accompanying diagram (fig. 5) of the oscillations of Lake Michigan illustrates the annual cycle and also the progressive changes from year to year. Being compiled from monthly means of gauge readings, it does not show tides and seiches nor the oscillations of short period.

These various oscillations of the water, though differing widely in amplitude, rate, and cause, yet coexist, and they make the actual movement of the water surface highly complex. The complexity of movement seriously interferes with the use of the water plane as a datum level for the measurement of earth movements, and a system of observations for that purpose needs to be planned with much care.

The main principles of such a system are, however, simple, and may readily be stated. The most important is that the direct measurement of the heights of individual points should not be attempted, but comparison should always be made between two points, their relative height being measured by means of the water surface used as a leveling instrument.

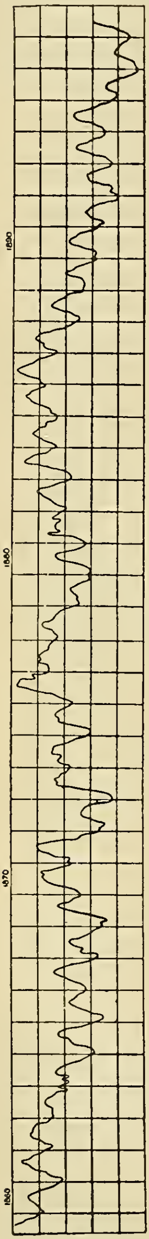

Fig. 5.

OSCILLATIONS OF THE SURFACE OF LAKE MICHIGAN, DUE TO CHANGES IN THE VOLUME OF THE LAKE.

Compiled under the direction of the Chief of Engineers, U. S. A., from gage readings at Milwaukee, Wis., from August, 1859, to June, 1897. Each horizontal space represents a calendar year; each vertical space 1 foot.

In the diagram, figure 6, A C B is the profile of a lake basin, A and B are fixed objects on opposite shores, and we will suppose the water surface to have the position X X′. Assuming the water in equilibrium, all parts of this surface have the same height. If the height of A above the water at X be accurately measured by the surveyor's level, and the height of B above the water at X′ be similarly measured, then the difference between these two measurements gives the difference in height between A and B. After an interval of some years or decades the work is repeated. The water surface then has some different position, Y Y′, and the heights measured are of A above Y and of B above Y′. The difference between the two heights gives, again, the relative height of A and B; and if earth movement has tilted the basin toward A or B, the change in their relative height may be shown by the difference in the two results of measurement.

As the water is in fact not still, but in continual motion, the mere running of lines of level from A and B to the water does not suffice, and it is necessary to determine from observations on the oscillating water surface what would be its position if still. Such observations are made by means of gages. These are of various forms, but each consists essentially of a fixed point, or zero, close by the water, and a graduated scale, by means of which the vertical distance of the water surface from the zero is measured.

Changes in the volume of the lake influence all parts of its surface equally and at the same time. To eliminate their effects from the measurements it is only necessary that the gage observations at the two stations be simultaneous. The effects of wind waves can be prevented by breakwaters. Disturbances due to currents propelled by strong winds can be avoided by choosing times when there is little wind. The effects of light winds can be approximately eliminated by taking the average of many observations, and so can the effects of seiches and tides. The effects of differences of atmospheric pressure can be computed from barometric measurements of air pressure, and the proper corrections applied. It is also possible, by the discussion of long series of observations at each station, to determine the local tidal effects and afterwards apply corrections; and the land and sea breeze effect may be treated in the same way.

In the investigation I was able to make, consideration was given to these various sources of error, but it was not practicable to take all desirable measures for avoidance or correction, because the reading of gages was only partly under my control. Gage stations have been established on the Great Lakes at various times and at various places, and the records of readings have been preserved. In some cases the zeros of gages were connected by leveling with bench marks of a permanent character, and in a few instances the gages themselves are stable and enduring structures. The most important body of information of this character is contained in the archives of the United States Lake Survey, which were placed at my service by the Chief of Engi-

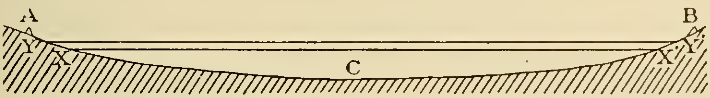

Fig. 6.

DIAGRAM ILLUSTRATING THE METHOD OF USING A LAKE SURFACE FOR THE DISCOVERY AND MEASUREMENT OF EARTH MOVEMENTS.

neers, United States Army. By searching the records I was able to select certain pairs of stations at which the relative heights of permanent points on the shore (equivalent to A and B of the diagram) had been practically determined twenty or more years ago. At some of these stations gages are still read; at others I established gages and ran the leveling lines necessary to connect them with the old benches. At all of them observations were maintained from July to October, 1896, and these observations, in combination with the levelings, afforded measurements that could be compared with those made earlier, so as to discover changes due to earth movement.

It will not be necessary to give here the details of observation and computation, as they are fully set forth in a paper soon to be printed by the Geological Survey,[1] but the general scope of the work may be briefly outlined. As the tilting shown by the geologic data was toward the south-southwest, stations were, so far as possible, selected to test the question of motion in that direction. The most easterly pair were Sacketts Harbor and Charlotte, New York, connected by the water surface of Lake Ontario. (See map, fig. 7.) From observations by the United States Lake Survey in 1874, it appeared that a bench mark on

[1] U. S. Geol. Surv., 18th Ann. Rept., Part II, pp. 595–647, 1898.

the old light-house in Charlotte was then 18.531 feet above a certain point on the Masonic Temple in Sacketts Harbor. In 1896 the measurement was repeated, and the difference found to be 18.470 feet, the point at Sacketts Harbor having gone up, as compared to the point at Charlotte, 0.061 foot, or about three-fourths of an inch. Similarly it was found that between 1858 and 1895 a point in Port Colborne, at the head of the Welland Canal, as compared to a point in Cleveland, Ohio, rose 0.239 foot, or nearly 3 inches. Between 1876 and 1896 a point at Port Austin, Michigan, on the shore of Lake Huron, as compared to a point in Milwaukee, on the shore of Lake Michigan, rose 0.137 foot, or 1½

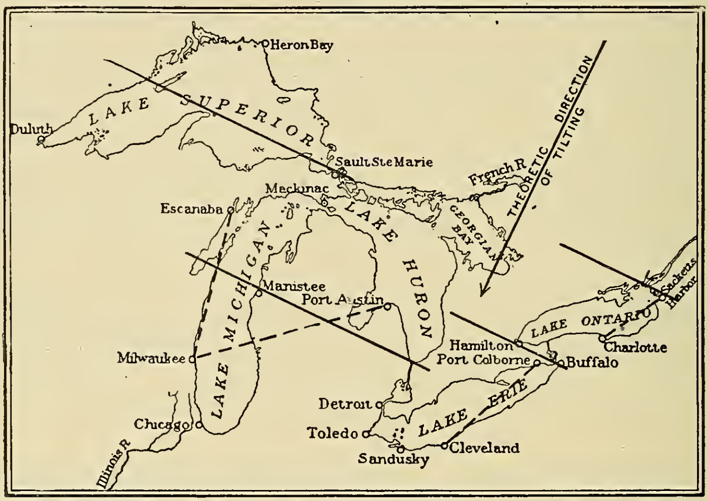

Fig. 7.

MAP OF THE GREAT LAKES, SHOWING PAIRS OF GAGING STATIONS AND ISOBASES OF OUTLETS.

The isobases are marked by full lines. Broken lines show the pairs of stations.

inches; and in the same period a point in Escanaba, at the north end of Lake Michigan, as compared to the same point in Milwaukee, rose 0.161 foot, or about 2 inches.

There is no one of these determinations that is free from doubt; buildings and other structures on which the benches were marked may have settled, mistakes may have been made in the earlier leveling, when there was no thought of subjecting the results to so delicate a test, and there are various other possible sources of error to which no checks can be applied; but the fact that all the measurements indicate tilting in the direction predicted by theory inspires confidence in their verdict. This confidence is materially strengthened when the numerical results are reduced to a common unit and compared.

Summary of distances, time intervals, and measurements of differential earth movements.

Pairs of stations.	Direct distance.	Distance in direction S. 27° W.	Interval between dates of measurements.	Change in relative height.	Change per 100 miles per century.	Probable errors of quantities in last column.
	Miles.	*Miles.*	*Years.*	*Feet.*	*Feet.*	*Feet.*
Sacketts Harbor and Charlotte	86	76	22	0.061	0.37	0.18
Port Colborne and Cleveland	158	141	37	.239	.46	.11
Port Austin and Milwaukee	259	176	20	.137	.39	.09
Escanaba and Milwaukee	192	186	20	.161	.43	.06
Mean					0.41	
Weighted mean					.42 ± 0.05	

The stations of the several pairs are at different distances apart, the directions of the lines connecting them make various angles with the theoretic direction of tilting, and the time intervals separating the measurements are different. To reduce the results to common terms, I have computed from each the rate of tilting it implies in the theoretic direction, S. 27° W. In the sixth column of the preceding table the rate is expressed as the change in relative height of the ends of a line 100 miles long during a century.

Compared in this way, the results are remarkably harmonious, the computed rates of tilting ranging only from 0.37 foot to 0.46 foot per 100 miles per century; and in view of this harmony it is not easy to avoid the conviction that the buildings are firm and stable, that the engineers ran their level lines with accuracy, that all the various possible accidents were escaped, and that we have here a veritable record of the slow tilting of the broad lake-bearing plain.

The computed mean rate of tilting, 0.42 foot per 100 miles per century, is not entitled to the same confidence as the fact of tilting. Its probable error, the mathematical measure of precision derived from the discordance of the observational data, is rather large, being one-ninth of the whole quantity measured. Perhaps it would be safe to say that the general rate of tilting, which may or may not be uniform for the whole region, falls between 0.30 and 0.55 foot.

While the credit of formulating the working hypothesis or geologic prediction which has thus been verified by measurement belongs to Spencer, it is proper to note that the fundamental idea of modern differential earth movement in the Great Lakes region was announced much earlier by G. R. Stuntz, a Wisconsin surveyor. In a paper communicated to the American Association for the Advancement of Science in 1869, he cites observations tending to show that in 1852–53 the water of Lake Superior stood abnormally high at the west end, while it was unusually low at the east, and he infers that the land is not stable.

The geographic effects of the tilting are of scientific and economic importance. Evidently the height of lake water at a lake's outlet is regulated by the discharge and is not affected by slow changes in the attitude of the basin, but at other points of the shore the water advances or retreats as the basin is tipped. Consider, for example, Lake Superior. On the map (fig. 7) a line has been drawn through the outlet at the head of St. Marys River in a direction at right angles to the direction of tilting. All points on this line, called the isobase of the outlet, are raised or lowered equally by the tilting and are unchanged with reference to one another. All points southwest of it are lowered, the amount varying with their distances from the line, and all points to the northeast are raised. The water, always holding its surface level and always regulated in volume by the discharge at the outlet, retreats from the rising northeast coasts and encroaches on the sinking southwest coasts. Assuming the rate of tilting to be 0.42 foot per 100 miles per century, the mean lake level is rising at Duluth 6 inches per century and falling at Heron Bay 5 inches. Where the isobase intersects the northwestern shore, which happens to be at the international boundary, there is no change.

Lake Ontario lies altogether southwest of the isobase of its outlet, and the water is encroaching on all its shores. The same tilting that enlarged it from the area marked by the dotted line of figure 2 is still increasing its extent. The estimated vertical rise at Hamilton is 6 inches per century. The whole coast of Lake Erie also is being submerged, the estimated rate at Toledo and Sandusky being 8 or 9 inches per century.

The isobase of the double lake Huron-Michigan passes southwest of Lake Huron and crosses Lake Michigan. All coasts of Lake Huron are therefore rising as compared to the outlet, and the consequent apparent lowering of the mean water surface is estimated at 6 inches per century for Mackinac and at 10 inches for the mouth of the French River, on Georgian Bay. In Lake Michigan the line of no change passes near Manistee, Mich. At Escanaba the estimated fall of the water is 4 inches per century; at Milwaukee the estimated rise is 5 or 6 inches, and at Chicago between 9 and 10 inches.

These slow changes of mean water level are concealed from ordinary observation by the more rapid and impressive changes due to variations of volume, but they are worthy of consideration in the planning of engineering works of a permanent character, and there is at least one place where their influence is of moment to a large community. The city of Chicago is built on a smooth plain, little above the high-water level of Lake Michigan. Every decade the mean level of the water is an inch higher, and the margin of safety is so narrow that inches are valuable. Already the older part of the city has lifted itself several feet to secure better drainage, and the time will surely come when other measures of protection are imperatively demanded.

Looking to the more distant future, we may estimate the date at which the geographic revolution prophesied by Spencer will occur. Near Chicago, as already mentioned, is an old channel made by the outlet of a glacial lake. The bed of the channel at the summit of the pass is about 8 feet above the mean level of Lake Michigan and 5 feet above the highest level. In five or six hundred years (assuming the estimated rate of tilting) high stages of the lake will reach the pass, and the artificial discharge by canal will be supplemented by an intermittent natural discharge. In one thousand years the discharge will occur at ordinary lake stages, and after fifteen hundred years it will be continuous. In about two thousand years the discharge from Lake Michigan-Huron-Erie, which will then have substantially the same level, will be equally divided between the western outlet at Chicago and the eastern at Buffalo. In twenty-five hundred years the Niagara River will have become an intermittent stream, and in three thousand years all its water will have been diverted to the Chicago outlet—the Illinois River, the Mississippi River, and the Gulf of Mexico.

THE PLAN OF THE EARTH AND ITS CAUSES.[1]

By J. W. Gregory, D. Sc.

THE VARIATIONS OF TOPOGRAPHIC FORM.

Despite the extreme variability in the shapes of the continents and their apparently capricious distribution, geographers of all ages have believed that the arrangement of land and water on the globe is based on a regular plan. The plan can, of course, only be recognized in broad outline, for the shape of the land masses depends on the structure of the earth forms, which vary indefinitely. Intricate mountain-valley systems open out to wide-flung rolling prairie, stoneless alluvial flats are broken by the crags of rock ridges, volcanic cones stand isolated like pyramids, while mountain chains run thousands of miles unbroken. Such contrasts are natural, as the land forms are the result of the struggle of complex forces with varying powers of attack against complex rock masses formed of materials having varying powers of resistance. Coast lines, for example, project where hard rocks repel the surf, where rivers deposit alluvium more quickly than the tide can remove it, or where the winds build up sand dunes, whose very weakness disarms the waves. Coast lines are indented where soft beds crumble under frost and rain, and where dominant winds, the inset of an ocean current, or an undulation on the sea floor directs a jet-like stream of water against the shore. Topographical form depends on so many incalculable, inconstant factors that the stages of its growth are often now untraceable. The missing links of geographical evolution are indeed as numerous as those of organic evolution, and the chapter of accidents is invoked by geographers to explain difficulties analogous to those for which naturalists appealed to the doctrine of special creation. But unexplained differences in the geographical units no more disprove an orderly progress in the growth of the continents than the existence of isolated, unexplained groups of animals is fatal to Darwinism. Such topographical differences are of secondary importance in contrast to the numerous coincidences and repetitions of the same essential form among the geographical units. Geographers accordingly

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[1] Read at the Royal Geographical Society, January 23, 1899. From The Geographical Journal, No. 3, March, 1899, Vol. XIII, pp. 225–251.

have believed that there is a hidden continental symmetry which, when discovered, will explain the law that has determined the distribution of land and water on the globe.

This idea dates from the dawn of geographical science. The early classical geographers noticed how the seas radiated from the Levantine area, and opened to a broad, boundless ocean. They accordingly described the land of the globe as an island, floating on a vast surrounding sea, whence channels converged toward the hub of the classical universe. This radial plan reappears in the mediæval wheel maps in which Jerusalem was accepted as the center of the world, whence the main geographical lines radiated like the spokes of a wheel.

These systems fell forever on the discovery of America, which could not be brought into conformity with the radial plan by even the ingenious devices of mediæval cartographers. Later on came an even worse blow. Geologists showed that, instead of the land areas being fixed and immutable, they are really more fickle and less enduring than the sea. The distribution of land is therefore constantly changing, owing to local variations in its level. The discovery of this truth seemed to destroy the very basis of any possible earth plan. Indeed, Lyellism, with its essential doctrine of the alternate elevation and subsidence of the land under the agency of local causes, seemed inconsistent with the existence of any general cause governing the geographical evolution of the globe as a whole.

But a truer appreciation of this later knowledge did not confirm these first deductions. America is now used as the typical or, to borrow a biological phrase, the schematic continent. And when, remembering the probability of local variations in land level, allowance is made for them, new resemblances are revealed, and exceptions that once were serious difficulties are removed. For instance, the oceans all end in triangles pointing to the north. This is the case with the Pacific, the two sections of the Indian Ocean, and the basins of the Mediterranean. The Atlantic alone is broadly open at its northern end. But Scotland and Iceland are connected by a submerged ridge, which is said to be capped by a line of old moraine. If this ridge were raised to sea level, the Atlantic would conform to the general rule by tapering northward to a point between Iceland and Greenland.

Similarly with the land masses. There seems at first sight no resemblance in shape between the Old World and the New. But the Old World is divided into halves by a band of lowland, which extends southward from the Arctic Ocean to the Caspian, and northward from the Arabian Sea up the Persian Gulf. There is evidence to show that the sea recently covered these northern lowlands and occupied the Persian depression; while somewhat earlier, in Miocene times, the intervening ridge was also submerged. Restore these conditions, and the continents would occur as three meridional belts, each broken across by transverse Mediterranean seas, viz, North and South America separated by the Caribbean depression; Europe and Africa (the Eurafrica of Professor Lapworth) separated by the Mediterranean; Asia and Australasia divided by the Malaysian folds.

Hence the oscillating character of the land, which appeared fatal to the old faith in an earth plan, helps to justify it, now that oceanography and geology have shown us how much to allow for the obscuring action of these changes of level.

But it is inadvisable, in attempting to explain the existing plan of the earth, to introduce any alterations in the distribution of land and water. For, although a geologist may have no doubt about such assumed changes, he can not expect geographers to have an equal faith in them, or even to take much interest in a world thus modified. The geographer is concerned with the existing arrangement of the world, and not with the more or less problematical plans of former ages. The introduction of earlier and more primitive geographical systems, though it would simplify the question, is unnecessary, since the existence of a present earth plan is clearly revealed by three striking facts.

GEOGRAPHICAL SYMMETRY.

Two of these facts are stated in every geographical text-book. They are evident on the most casual examination of a map. The first is the concentration of land in the Northern and of sea in the Southern Hemisphere. The second is the triangular shape of the geographical units. The continents are triangular, with the bases to the north. The oceans are triangular, with the bases to the south. Accordingly the land forms an almost complete ring round the North Pole, and from this land ring three continents project southward. The oceans form a continuous ring round the South Pole, and from it three oceans project northward into the angles between the continents. The belts of sea and land are fixed on the earth's axis like a pair of cogwheels with interlocking teeth. These two belts may be referred to as the northern land belt and southern oceanic belt.

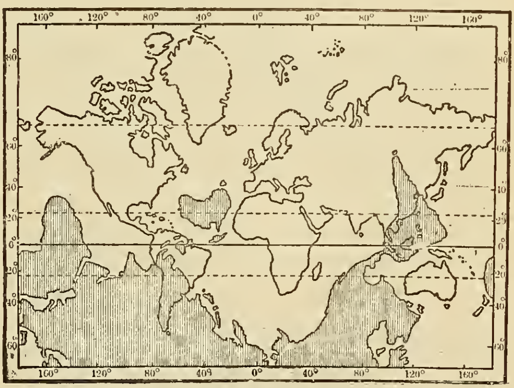

Fig. 1.

MAP OF THE WORLD, SHOWING THE DISTRIBUTION OF ANTIPODAL AREAS.

The third striking feature in the earth's physiognomy is less conspicuous, but is even more significant. It is known as the antipodal arrangement of oceans and continents. It is most easily recognized by examination of a globe; but it can easily be illustrated by a plain map. The antipodes of a point in the center of the continent of North America occurs in the Indian Ocean; and if we mark on a map the antipodes of all the points in North America, we should find that the whole of that continent is exactly antipodal to the Indian Ocean. Similarly, the elliptical mass of Europe and Africa is antipodal to the central area of the Pacific Ocean; the comparatively small continent Australia is antipodal to the comparatively small basin of the North Atlantic; the South Atlantic corresponds—though less exactly—to the eastern half of Asia; and the Arctic Ocean is precisely antipodal to the antarctic land.

These, then, are the three fundamental facts in the existing plan of the globe. Our main problem is, Why are the geographical elements thus shaped and thus distributed?

THE EARTH'S CONCENTRIC SHELLS.

It simplifies the statement of the problem to remember that the earth consists of three parts: There is the vast unknown interior, or "centrosphere," concerning which physicists have not come to any unanimous decision, some saying that it is throughout solid and rigid, others that it is partly fluid, and others again that it is partly gaseous. This interior mass is inclosed by a shell formed of two layers, the solid crust, or "lithosphere," and the oceanic layer, or "hydrosphere." It is possible that at first the two layers of the shell were regular and uniform, in which case the whole world was covered by a universal ocean; but before the dawn of geological history this arangement had been disturbed by the formation of irregularities in the surface of the lithosphere. Dry land appeared at the areas of elevation, and the waters gathered together into the intervening depressions.

The problem, then, of the distribution of land and water on the globe is the problem of the distribution of irregularities in the surface of the lithosphere. We are accordingly at once brought face to face with the question, When were the existing irregularities made? If, as many authorities say, these depressions date from the earliest days of the earth's history, and have lasted unchanged in position throughout geological time, then we are thrown back upon some cause which acted when the earth was in its infancy. In that case the question is astronomical and physical, instead of geological and geographical.

PRE-GEOLOGICAL GEOGRAPHY.

There have been several attempts to solve the question astronomically, of which the most important is that of Prof. G. H. Darwin. According to his luminous theory the tidal action of the sun on the viscous earth formed two protuberances at opposite points of the equator; one of the protuberances broke away and solidified as the moon, which revolved round the earth much nearer than at present. As a new equatorial protuberance formed the moon pulled it backward, thus causing a series of wrinkles in the earth's crust, which persist as the main structural lines of the continents. These wrinkles ran at first north and south from the equator. But, owing to the moon's strong pull on the equatorial girdle, this part of the earth would tend to revolve more slowly than the polar regions. Hence the primitive wrinkles were deformed; instead of being meridional in direction, they would trend northeasterly in the northern hemisphere, and southeasterly in the southern hemisphere. Professor Darwin points out that some of the most striking geographical lines on the earth run in accordance with this plan. He instances the eastern coast of North America, the western coast of Europe, part of the coast of China, and the southern part of South America. But, with characteristically Darwinian frankness, he does not overpress the facts, admits that the resemblances are not so convincing as they might be, and that some cases—e. g., the western coast of North America—are absolutely inconsistent with the scheme.

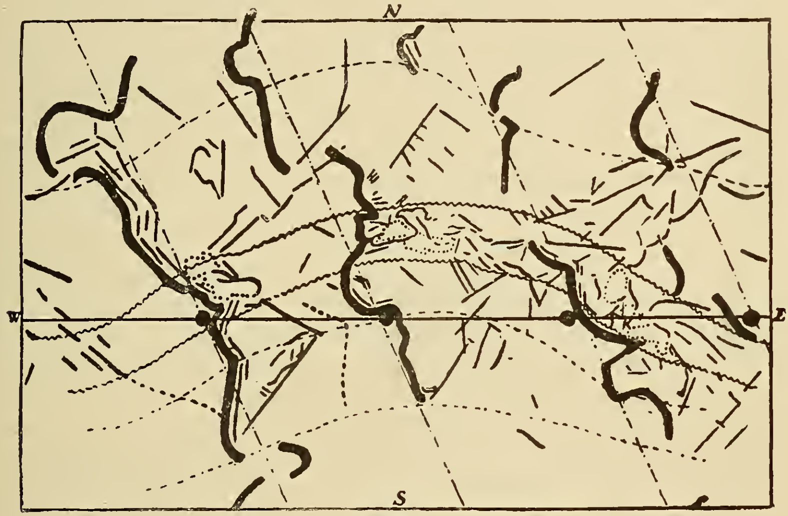

Fig. 2.

THE OBLIQUE COURSE OF THE MAIN GEOGRAPHICAL LINES. (AFTER PRINZ.)

Another theory that attributes the formation of the main geographical lines to pregeological incidents is given in a paper by Prinz, "Sur les similitudes que presentent les cartes terrestes et Planétaires," which elaborates and gives an astronomical basis to ideas previously suggested by Lowthian Green and Daubrée. His theory is that the northern part of the earth had a lower angular velocity than the equatorial and southern regions. Therefore the land masses in the southern hemisphere were gradually pushed forward toward the east. The line between the northern retarded hemisphere and the southern swifter hemisphere is the great line of weakness and fracture that runs from the Caribbean along the Mediterranean, down the Persian Gulf and across Malaysia. Prinz has drawn a map (fig. 2) showing how the main geographical lines agree with his assumed lines of torsion.

This map is interesting, for these primitive torsion wrinkles must have been formed in the same period as Professor Darwin's primitive tidal wrinkles. It is significant that the lines do not correspond. The chief geographical lines which Darwin claims as his primitive wrinkles are inexplicable on Prinz's theory, and the great lines which Prinz claims to support his wrinkling are opposed to those of Darwin. The geographical primitive lines of the two theories are often contradictory.

A third theory assigning the geographical distribution to very ancient causes has been proposed by Professor Lapworth. In an address to the geographical section of the British Association in 1892, and in a brilliant lecture on "The face of the earth," delivered to the Royal Geographical Society in 1894, Lapworth attributed the arrangement of oceans and continents to an intercrossing series of primitive earth folds. The oceans, according to this theory, occupy ancient basins of depression; and the continental masses are domes of elevation.

"The surface of the earth crust at the present day," says Lapworth, "is most simply regarded as the surface of a continuous sheet which has been warped up by two sets of undulations crossing each other at right angles * * * The one set ranges parallel with the equator, and the other ranges from pole to pole." Professor Lapworth contends that the intersecting of two simultaneous orthogonal sets of undulations explains the forms and dispositions of the continents, the triangular shapes of their extremities, the diagonal trends of their shores, and the course of the linear archipelagoes. In some interesting diagrams he suggests why the intersecting nodal lines which mark the divisions between the areas of elevation and of depression should coincide with the steep slopes that separate the ocean floors and the continental platforms; and why the existing shore lines should so often run diagonally between the meridians and parallels.

This theory, and that of Sir John Lubbock, which also attributes the continental forms to a double intercrossing series of folds, have the advantage over the astronomical theories of more detailed agreement with geographical facts; but Professor Lapworth has not, so far as I am aware, explained what caused his intersecting folds. His theory is accordingly less complete than the others, as it is rather a statement of facts than an explanation of causes.

These suggestive theories are open to one objection which seems fatal to their application to the existing geographical plan. We should expect from them that the main geographical structure lines in the northern and southern hemispheres should be either symmetrically arranged or continuous on both sides of the equator. But that the land systems of the two hemispheres are asymmetrical is the most glaring fact in geography. It may be urged that the primitive folding, wrinkling, and torsion formed a symmetrical or continuous land system, and that the asymmetrical arrangement is due to later movements. In that case the theories are geographically inadequate, because they give no explanation of how the existing geographical asymmetry was developed.

But there is another and still more serious objection which applies to all three theories. They not only explain too little, but they explain too much. The primitive lines of these systems often coincide with features of modern development, and are inconsistent with the old-established geographical arrangements. For instance, Professor Darwin quotes the trend of the western coast of Europe from Spain to Norway as in accordance with his scheme. Prinz makes the primitive line here run exactly at right angles to Darwin's line; and geological evidence favors Prinz. The coast line from Spain to Norway is almost certainly of modern date, while the lines of wrinkling, both Hercynian and Alpine, run transversely to the direction which they ought to have followed if due to tidal strain. Moreover, Professor Darwin quotes the western coast of North America as inconsistent with his theory; but that coast is parallel to a line of primitive wrinkling, for there is an Archean protaxis to the coast ranges and Rocky Mountains.

Prinz's torsion wrinkles are no better. The most striking case of apparent agreement between his theory and geography is the trend of the Andes and Rocky Mountains. Professor Lapworth also lays stress on "the great Rocky Mountain-Andes fold * * * the longest and most continuous crust-fold of the present day."[1] The agreement was important so long as the Rocky Mountains and the Andes were regarded as a single mountain system, connected into a continuous line by a mountain axis running north and south across Central America. But that axial mountain chain in Central America is a myth. Central America is traversed by a series of ridges which run east and west, and not north and south.[2] The watershed, it is true, runs along the Pacific border, but that is due to a movement later than the mountain ridges which are thus truncated. The continuation of the Andes is in the mountains of Venezuela, not in North America or the Sierra Nevada. The Andes and the mountain system of the Western States of America are essentially distinct; they differ in every important respect, geological structure, geographical characters, and dates of formation. Any theory which assigns the Andes and the great mountain series on the western coast of North America to a common origin is thereby prejudiced, instead of being supported.

These three theories assign the earth plan to a venerable antiquity; but there is a fourth theory, which carries it back to an antiquity even more venerable. Lord Kelvin attributes the oceanic and continental areas to a chemical segregation in the gaseous nebula which was the parent of the earth. According to this theory "Europe, Asia, Africa,

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[1] The term "Rocky Mountains" is here apparently used for the Sierra Nevada and Coast Range series of British Columbia. The true Rocky Mountains are at a great distance (ranging up to 1,000 miles) from the Pacific coast, the trend of which they do not determine.

[2] E. g. the Sierra Candela, Cordillera de Dota, Sierra Chiriqui, Sierra Veragua, Cordillera de San Blas, etc.

America, Australia, Greenland, and the Antarctic continent, and the Pacific, Atlantic, Indian, and Arctic ocean depths, as we know them at present," were all marked out in the primeval gaseous nebula. These gaseous continents condensed to liquid continents, marked off from the suboceanic areas by chemical differences; and these liquid continents were fixed as the solid continents, heightened by shoaling as the molten globe and its last lava ocean solidified.

That theory appears probable with one verbal amendment—the substitution of the term "archæan blocks" for continents. That these

Fig. 3.

THE MOUNTAIN SYSTEM OF CENTRAL AMERICA. *a*, VOLCANIC CHAIN OF HEREDIA; *b*, SIERRA CANDELLA; *c*, CORDILLERA DE DOTA; *d*, SIERRA CHIRIQUI; *e*, SIERRA VERAGUA; *f*, CORDILLERA DE SAN BLAS; *g*, VOLCANIC CHAIN OF ALAJUELA.

archæan blocks—the earth's great corner stones—were embryonically outlined by chemical segregations in the molten or gaseous stages of the earth seems probable. But these archæan corner stones, though the foundations of the continents, are not the continents. Lord Kelvin's theory suggests no explanation why chemical segregations should have assumed the shapes of the continents, so that his explanation rests on an unexplained cause; and even if his theory be amended by application to the archæan blocks instead of to the continents, the theory is geographically insufficient, as it does not show the relation between the archæan blocks and the existing continents.

THE PERMANENCE OF CONTINENTS.

That Lord Kelvin's nebulous segregations, Professor Darwin's primitive wrinkling, Sir John Lubbock and Professor Lapworth's double folds are all true causes seems probable. What is doubtful is whether any extensive trace of their influence can be discerned in the present distribution of land and water. A map of the world in early Cambrian times might show the influence of these pregeological incidents; but their geographical effects seem to have been obliterated by the changes of geological times.

Reference to such changes reminds us that we can not assume their occurrence without considering the unending controversy as to the supposed permanence of oceans and continents.

There are, it must be conceded, many weighty arguments in favor of the permanence hypothesis. Many of the last great mountain foldings follow the lines of much older movements; and if the mountain axes, the "backbones of the continents," have occupied the same positions, why not also the continents molded upon them? Again, some of the great mountain chains, such as the Andes, run parallel to the nearest shore line, as if the movements that formed them had been deflected by the ocean basin.

The character of the ocean floors, moreover, suggests that they have never been continental, as they are at present covered by deposits not known in the interior of the continents, and as they are supported by material much heavier than that which forms the foundations of the continents.

These arguments, however, are not conclusive. Great earth movements of one date often cut obliquely and transversely across those of earlier periods. Thus the old northwesterly and southeasterly movements of France and Spain have been cut across by the east and western movements of the Pyrenean-Alpine system. Mountain axes have not always been deflected by or limited by existing ocean basins. Thus the north Atlantic basin cuts directly across the old Hercynian mountain chains, which may at one time have extended across the whole Atlantic channel. This is rendered probable by three lines of evidence. Thus in northwestern France, and in the south of the British Isles, there is a series of ranges trending north of west which is cut off abruptly by the Atlantic slope. On the opposite shore of the Atlantic in Newfoundland there is a similar series of truncated ranges formed at the same age as those of western Europe, and having the same trend. Bertrand maintains (1887) that the resemblance between the opposite mountain series is so striking that they should be regarded as parts of one mountain system, of which the central part has been sunk below the Atlantic. The well-known telegraph plateau on which the cables rest may mark the site of this sunken land. Palæontological evidence also supports the formation of the Atlantic by subsidence; for a shallow water, subtropical, marine fauna ranged from the Mediterranean to the Caribbean, and can only have crossed along a belt of shallow water in tropical or subtropical latitudes. Direct evidence of the existence of shallow water, continental deposits of the age required is given by the Azores, which, although now separated from Europe by a deep depression, contain shallow water deposits with fossils of the Mediterranean fauna.

Thus there is strong evidence to show that the Atlantic, in its present form, is of no great geological antiquity, and Suess's theory of its origin continually gains stronger support. Similar, though less complete, evidence shows that the other ocean basins have been broken up along certain lines, and emphatically denies their entire permanence throughout geological times.

ÉLIE DE BEAUMONT'S "PENTAGONAL RESEAU."

Hence, if the ocean basins were not formed pregeologically, but have grown from the changes that have occurred during the long ages of geological time, then we must seek for a cause that has acted continuously and is acting to-day. A more permanent cause is supplied by the contraction of the earth's crust, as the globe gradually cools. Since the cold, hard crust is less plastic than the hotter interior, it is necessarily crumpled as it is forced into a smaller space.

This idea is well known, as it has been invoked by geologists to explain the formation of folded mountain chains. That the mountain systems of the world were formed by this agency is improbable; but it is perhaps still too much to say that it is impossible. For Prof. G. H. Darwin has suggested that the contractility of the rocky crust has been exaggerated, and it has been shown that Reade's level of no strain may lie much deeper than was at first thought.

That secular contraction is the direct cause of the great fold-mountain systems is however less widely believed by geologists than it once was; but it may have an important influence in determining their direction. The trend of the great chains of fold mountains is to us a significant question, because there is much truth in the phrase, proverbial since its use in 1682 by Burnet in his "Theory of the earth," which describes the mountain chains as the "backbones of the continents." The first geological attempt to explain the plan of the earth was based on this belief. The author of this system was the French geologist Élie de Beaumont, whose theory of geomorphogeny was stated at length in his "Notice sur les systèmes de montagnes" (3 vols., Paris, 1852). This famous theory was based on a correlation of the mountain chains by means of their orientation. Élie de Beaumont accepts the view that the earth consists of a thin rigid crust surrounding a fluid, solidifying interior. The crust being thin, it necessarily collapses as the internal mass contracts. He assumes that these collapses occur at intervals of time. and that at these collapses the crust is broken along lines of weakness, which are crumpled up into mountain chains. He assumes that for practical purposes the earth's crust may be taken as homogeneous; hence that the fractures of the crust would be regularly distributed, and those of successive periods would cross one another along the lines of a regular symmetrical network.

Among the regular simple geometrical forms that known as the pentagonal dodecahedron, which is inclosed by twelve equal regular pentagons, possesses an exceptionable degree of bilateral symmetry, i. e., it can be cut into exactly similar halves in an unusually large number of directions. Sections along any of the edges of any of the pentagons and through the center of the pentagonal dodecahedron divide it into equal and similar halves. So, also, do sections from the center of the pentagons to any of the angles, and likewise sections across the pentagons from alternate angles. Each face of a pentagonal dodecahedron may therefore be divided by fifteen planes of symmetry.

A sphere may be described upon the pentagonal dodecahedron, so that all the corners (or, to use the correct term, solid angles) occur in the surface of the sphere. By joining the corners by lines the sphere is marked off into twelve spherical pentagons, which possess the same amount of symmetry as the plane pentagons. The lines where these planes of symmetry cut the surface of the sphere form a network of spherical triangles. Such a network Élie de Beaumont called his pentagonal network, and he used it in the following way: He studied the mountain ranges of the world, and by elaborate calculations showed their relative directions at a few localities which he chose as centers of comparison. He found that many mountain ranges have the same orientation and that others cross the first set at definite regular angles. The directions of the different sets of mountain ranges coincide with the lines of his pentagonal network. Élie de Beaumont claimed that the mountains whose directions are parallel[1] were formed at the same date. Successive mountain-forming movements raised chains parallel to different edges of the network, and thus the intersecting mountain lines of the world, and consequently the forms of the continents, were determined.

Élie de Beaumont had no difficulty in pointing out striking coincidences between important geographical lines and his pentagonal network. Thus the Mediterranean volcanic axis, passing through the Grecian archipelago, Etna, and Teneriffe, is parallel to the Alpine chain and at right angles to the circle through Etna, Vesuvius, Iceland, and the Sandwich Isles. He was able to show a close geometrical relationship between those lines and the line of the Andes, with the pentagon that covers Europe. That the earth is traversed by great intersecting lines is undeniable. E. g., Daubrée showed that the valley system of northern France follows a line of rectangular fractures, which

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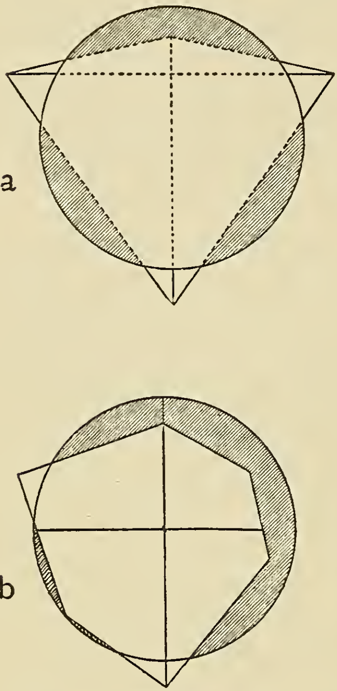
[1] For explanation and justification of this use of the word "parallel," see Hopkins, "Presid. Address, Geol. Soc.," Quart. Jour. Geol. Soc., Vol. IX, p. xxix.

he called diaclases. The directions of the Greenland fiords is determined by a similar series of intersecting diaclastic fractures. Bertrand has shown that the movements in the Paris Basin, the North Sea, and English Channel have followed a double set of orthogonal intersecting lines.

But that the fracture lines or lines of weakness in the earth's crust should intersect more or less rectangularly is natural on any theory of their formation. And such coincidences as those pointed out by Élie de Beaumont in support of his system are inevitable in so crumpled a globe as ours, but they are not sufficiently numerous to be convincing, especially in face of the fundamental differences between the facts of geography and Élie de Beaumont's elaborate artificial system. His theory could only be applied to a symmetrical world;[1] in a dodecahedron the opposite faces are always similar and parallel; in Élie de Beaumont's network the antipodal areas are always similar. But, as we have seen, the fundamental fact in the plan of the world is that opposite areas are dissimilar. In crystallographic language, the lithosphere is hemihedral, not holohedral, and no scheme based on a holohedral form will serve. It is the recognition of this principle that led to the next great advance.



4a

4b

Fig. 4.

RELATIONS OF A TETRAHEDRAL LITHOSPHERE TO ITS HYDROSPHERE. FIG. 4a REPRESENTS THE ARRANGEMENT IN A SIMPLE TETRAHEDRON. FIG. 4b ILLUSTRATES THE CASE OF A MODIFIED TETRAHEDRON (SUCH AS SHOWN IN FIG. 5b), BY A SECTION PASSING ON THE LEFT THROUGH A TETRAHEDRAL COIGN, AND ON THE RIGHT THROUGH THE OPPOSITE TETRAHEDRAL FACE. THE SHADED AREAS REPRESENT WATER.

THE TETRAHEDRAL THEORY.

Élie de Beaumont's scheme is now mainly of historic interest, though Lefort's recent map of the Nivernais shows that it is still used as a working hypothesis by some French geologists. But Élie de Beaumont's theory marked an epoch in this subject, for it led to the system of Mr. Lowthian Green, which far better meets the requirements of the case.

This system was founded in 1875, by Mr. Lowthian Green, in a work which was neglected or ridiculed at the time of its appearance. Like

[1] This objection applies also to various later modifications of Élie de Beaumont's principle, such as those of Owen, or to the more than local acceptance of the diaclases of Daubrée or orthogonal cross folds of Bertrand.

his predecessor, Green assumes that the earth is a spheroid based on a regular geometrical figure. He adopted as his base the apparently hopelessly unsuitable figure of the tetrahedron, which is contained within four equal similar triangles. This form, with its four faces, six sharp edges, and four solid corners, does not conform to the ordinary conception of the figure of the globe. Any comparison between them looks ridiculous. But if we place a three-sided pyramid on each side of the tetrahedron, its proportions are nearer those of a globe; and if these pyramids had elastic sides, so that they could be blown out and the faces thus made curved, then the tetrahedron would become spheroidal and even spherical. Conversely, if a hollow sphere be gradually

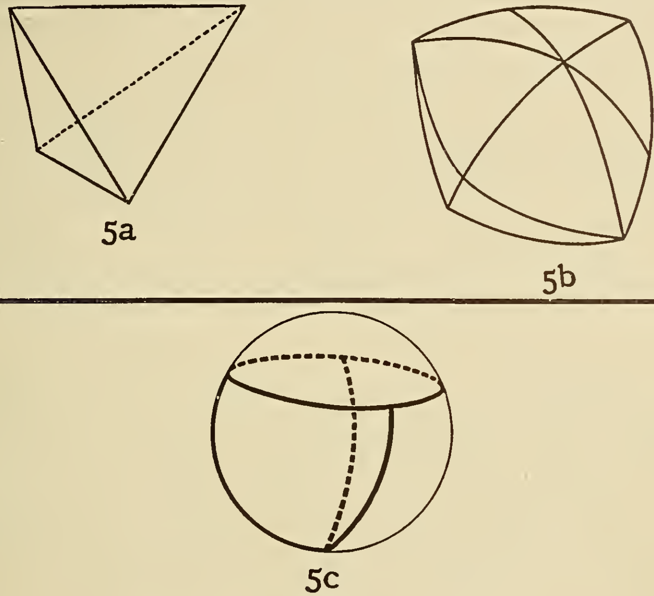


Fig. 5.

5a, DIAGRAM OF A SIMPLE TETRAHEDRON.—5b, DIAGRAM OF A TETRAHEDRON WITH A SIX-FACED PYRAMID WITH CONVEX FACES ON EACH OF THE FOUR FACES.—5c, THE TRACE OF THE TETRAHEDRAL EDGES ON A SPHERE; THE THICK LINES SHOW THE POSITION OF THE TETRAHEDRAL EDGES.

exhausted of air, the external pressure may force in the shell at four mutually equidistant points, and, by the flattening of these four faces, make it tend toward a tetrahedral form. Now the tetrahedral theory does not regard the world as a regular tetrahedron with four plane faces. It considers that the lithosphere has been subjected to a slight tetrahedral deformation, to an extent indeed only faintly, if at all, indicated by geodetic measurements, but yet easily recognizable owing to its influence on the distribution of land and water. As the centers of the flattened faces are nearer the earth's center of mass than the edges, the water will collect upon them. The ratio of the area of land to that of water on the globe is as 2 to 5. If on a model of a tetrahedron we color the five-sevenths of the surface that is nearest the center, the colored areas would show where the water would collect if the earth were a stationary tetrahedron. On the upper face there is a large central colored area in the position of the Arctic Ocean. It is surrounded by a land belt, from which three projections run southward down the three lateral edges. These three land areas taper southward to a point, below which is a complete belt of sea. South of that, again is our fourth projecting corner, which is above the water level, and is the Antarctic Continent. So that on the model the general plan of the arrangement of land and water is identical with its actual distribution on the globe. For the land occurs as three triangular equidistant continents, united above into a ring and tapering southward; there is a great excess of water in the Southern and of land in the Northern Hemisphere; and land and water are antipodal, since in a tetrahedron a corner is always opposite a flat face.

But of course in the earth the faces are not flat, but are convex. If the flat faces be replaced by projecting pyramids with curved faces, so that the form is globular, the arrangement of land and water remains the same, but the shore lines are more complex. Green has shown what the shapes of the land and water areas would be in such a tetrahedron. The resemblance between his diagrammatic continent and Africa and South America, and between his ocean and either the Pacific, Indian Ocean, and South Atlantic, is very striking.

THE TETRAHEDRAL COURSE OF GEOGRAPHICAL LINES.

The agreement between the facts of geography and the tetrahedral theory goes further. The four faces of a tetrahedron meet along six edges, which should be lines of elevation on a globe. The trace of the edges of a tetrahedron on a surrounding sphere form a circle in the Northern Hemisphere, and three vertical or meridional edges meeting at the South Pole. In the earth the major watersheds have exactly this arrrangement. The great watershed of Eurasia, dividing the northern and southern drainages, runs, not along the main mountain axis, but far to the north of it, between the parallels of 50° and 60°. The northern and southern slopes of North America are separated by a divde along the same latitude. The southern watersheds, instead of following the lines of highest mountains, or the middle line of the continents, run close to the coast lines; the three watersheds mark the three vertical tetrahedral edges, and they occur at almost the theoretical distances, 120° apart.

Similarly with the mountain chains. As Sir John Lubbock has pointed out, "In the Northern Hemisphere we have chains of mountains running east and west—the Pyrenees, Alps, Carpathians, Himalayas, etc.—while in the Southern Hemisphere the great chains run north and south—the Andes, the African ridge, and the grand boss which forms Australia and Tasmania." That is to say, the northern mountains are parallel to the upper edges and the southern mountains parallel to the meridional edges of the tetrahedron.

THE CAUSE OF THE TETRAHEDRAL PLAN.

The statement that the elevations of the lithosphere are tetrahedral in arrangement is not a hypothesis, but a simple statement of geographical fact. Is the fact a mere coincidence? On the contrary, there are good reasons why the earth should acquire such a tetrahedroid symmetry. When the earth solidified it would (neglecting the influence of rotation) have contracted into a spherical shape. It would have tended to acquire this form because the sphere is the body which incloses the greatest volume for a given surface. But as the earth contracts it tends to acquire a shape in which there is a greater surface in proportion to its bulk. Now, among the regular geometrical figures

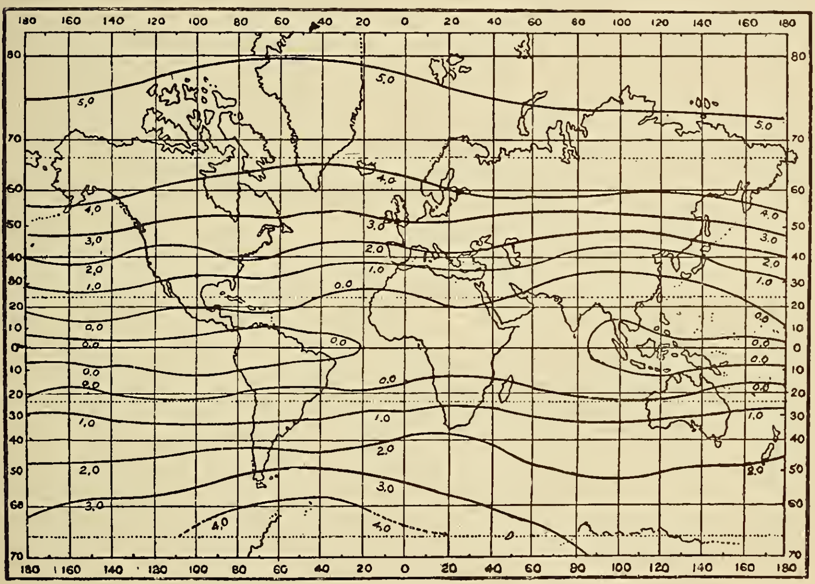


Fig. 6.

STEINHAUSER'S MAP, SHOWING VARIATION IN ATTRACTION OF GRAVITY, AS INDICATED BY LENGTH OF THE SECOND-BEATING PENDULUM. 0 = LENGTH IN EQUATORIAL BELT; 1-5 = NOS. OF MILLIMETRES BY WHICH PENDULUM HAS TO BE LENGTHENED IN ORDER TO BEAT SECONDS AT DIFFERENT LATITUDES.

with approximately equal axes the tetrahedron is that which contains the smallest volume for a given surface. Hence every hard-shelled body which is diminishing in size, owing to internal contraction, is constantly tending to become tetrahedral in form. Fairburn's experiments (quoted by Green) illustrate this tetrahedral collapse for short tubes; and that it is considered probable by some geodists is shown by the following quotation from E. D. Preston:

"Nothing is more in accordance with the action of physical laws than that the earth is contracting in approximately a tetrahedral form. Given a collapsing homogeneous spherical envelope, it will assume that regular shape which most readily disposes of the excess of its surface dimensions, or, in other words, the shape that most easily relieves the tangential strains; for, while the sphere is of all geometrical bodies the one with a minimum surface for a given capacity, the tetrahedron gives a maximum surface for the same condition. Experiments on iron tubes, on gas bubbles rising in water, and on rubber balloons all tend to bear out the assumption that a homogeneous sphere tends to contract into a tetrahedron."

THE EARTH A GEOID.

But it may be said this tetrahedral theory is impossible, because we know from our elementary text-books that the earth is not tetrahedral, but is an oblate-spheroid—that is to say, a sphere slightly flattened at the poles.

The oblate spheriod is no doubt the form that rotation would have caused the earth to assume as it solidified if the earth were quite homogeneous. But the earth is not homogeneous; it varies in strength and density, and an unequal load on the earth in any area leads to a divergence there from the circular shape. It is, I believe, now universally admitted that the earth is flattened laterally at the equator as well as at the poles. The question was long disputed between the astronomers, who, from theoretical considerations, declared what the shape of the world ought to be, and the geographers, whose measurements showed what the shape actually was. There is now a general agreement that the geographers were right; that the equatorial section of the earth is elliptical, similar to a section through the earth passing across the poles. The earth is therefore not a true spheriod, and it was accordingly regarded as an ellipsoid with three unequal axes. But there is good reason to believe that the earth is not even an ellipsoid, for the Northern and Southern hemispheres are unlike, and the earth is therefore shaped like a peg top. This is shown in two ways. It is a well-known property of the ellipse that degrees measured along the flatter side are longer than degrees measured near the sharper end. It was by proving that a degree of latitude in Lapland is longer than a degree of latitude in Ecuador that the French astronomers in the seventeenth century definitely proved the earth's flattening at the poles. In continuation of these observations La Caille, in 1751, measured the length of a degree at the Cape of Good Hope. His measurements showed that the Southern Hemisphere was also flattened, but to a different extent than the Northern Hemisphere. This anomalous result of La Caille's was confirmed and extended by Maclear.

The inequality of the two hemispheres has also been shown by the variations of gravity in the two hemispheres, which, as it is more easily tested, has been more widely applied. The principle is simple. A pendulum swings more rapidly the nearer it is brought to the center of the earth. A pendelum swings more slowly on a mountain top than at sea level. It was because Richer, in 1672, found that a clock which kept correct time in Paris lost two minutes a day in French Guiana that the polar flattening was first suspected. So many observations have been made that maps have been compiled showing the variation of the force of gravity throughout the globe. Figure 6 is a copy of Steinhauser's map, in which the variation of gravity is illustrated by showing how many millimeters have to be added to the length of a pendulum which beats seconds at the equator to make it vibrate at the same rate elsewhere. In both Northern and Southern hemispheres the second-beating pendulum has to be steadily lengthened as we approach the poles, but the deviation is at a different rate for the two hemispheres. The surface of the Southern Hemisphere does not approach the earth's center of mass at the same rate as the Northern Hemisphere. If the earth's center of mass is at its geometrical center, then the earth's form is elongated southward like a peg top. It is often held that the earth's center of mass is to the south of its center of form, because of the accumulation of water in the Southern Hemisphere. It is held that the water is piled up there owing to the greater density of the Southern Hemisphere. If that be the case, then the peg-top elongation is all the greater.

Moreover, there is evidence to show that the earth's figure is still more irregular than that of a peg top.[1] Sir John Herschel, although taking the astronomical side in the controversy, aptly stated the facts in the statement that "the earth is earth-shaped." Listing's name of geoid, which expresses this view, has now supplanted the old oblate spheroid from everything except the text-books. That there are local deformations in the earth's shape is demonstrated by the differences between the astronomical and trigonometrical determination of positions. Places have two different longitudes, the astronomical longitude obtained by astronomical observations, and geodetic longitudes determined by terrestial measurements; the differences are often considerable. It was calculated, e. g., that the trigonometrical and astronomical determination of the stations used in the delimitation of the Canadian and United States frontier should have agreed within 40 feet, or 0.4 of a second of arc; but the average error was more than five times as great, and ran up to eighteen times as much as it should have been.

Astronomical determinations, moreover, are often not only inconsistent with geographical measurements, but they are often inconsistent with themselves. For example, one of the most refined estimations of longitude that has yet been attempted, is the series undertaken by the "K. K. topographische militär Institut" of Vienna. To insure accuracy during these observations the most elaborate precautions were taken. Corrections were even made for the effect of the doses of quinine which the astronomers took when working in malarial climates. In one of the series of observations the difference in longitude between Vienna and Milan was determined first directly, and then by determining the difference between Vienna and Brescia and that between Brescia and Milan. But in spite of all the care the results did not tally. The sum of the two differences was not the same as the single

[1] As Professor Darwin suggests, potato-shaped would be a more correct simile.

difference. The whole, in fact, in this case was less than the sum of its parts.

To astronomers it may seem an unnecessary waste of time to devote so much to proving these deformations from the "spheroid of reference." But as the idea is less familiar to geographers and geologists, the insistence of this deformation may not be useless. It may be worth while adding a quotation from Prof. C. A. Young,[1] to show that the spheroid of reference is only a convenient assumption. "On the whole," says Professor Young, "astronomers are disposed to take the ground that since no regular geometrical solid whatsoever can absolutely represent the form of the earth, we may as well assume a regular spheroid for the standard surface, and consider all variations from it as local phenomena, like hills and valleys."

As deviations from the assumed spheroid of reference exist, it remains to inquire whether there is any evidence that they agree in position and arrangement with the theory of the tetrahedral deformation of the lithosphere.

The evidence already quoted of the dissimilarity between the northern and southern hemispheres and the elongation of the latter, is geodetic proof of the northern flattening and the antarctic projection, i. e., of one face and one tetrahedral corner.

The three flattened lateral faces and three projecting vertical edges are sufficiently demonstrated by the three great oceans and the land-lines that divide them. Practically, all the theories agree upon that point. It is well known that gravity is greater than was expected at most oceanic islands. Lallemand and de Lapparent have suggested that this is due to those islands being below the level of the ordinarily accepted figure of the earth, and therefore nearer the earth's center of gravity.[2] Fisher has suggested that the Pacific Ocean is the hollow left by the loss of the material which forms the moon. Faye has explained the ocean basins and the greater density of the crust below them as due to more rapid refrigeration below the cold oceanic abysses. According, therefore, to Faye, the rocks below the oceans contracted more than those below the continents, became denser, and accordingly sank.

Thus from all points of view the three oceans represent areas of depression, and the three land lines of South America, Africa, and Australasia mark intervening projections. The oceans mark the low areas in the lithosphere as obviously as the bubble of a spirit level marks its higher end; and they give, therefore, evidence of the triangular lateral flattening of the southern half of the globe.

But as, on the mathematical figure of the earth, such lateral flatten-

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[1] C. A. Young, General Astronomy, p. 101. 1889.

[2] This explanation is inadequate, as it does not explain the deviation of the pendulum on coast line toward the ocean. The excess vertical attraction of the islands has been explained as due to the attraction of the mass of the island and its base.

ing is more improbable than variations along the axis of rotation, let us consider whether there is any geodetic proof of these flattened faces and projecting edges.

There has been a long controversy as to whether Bessel's or Clark's ellipsoid better represents the figure of the earth. Clark's figure was the later in date, and is generally considered as the more exact. Helmert therefore expresses some surprise that the gravitational observations in central Europe along the fifty-second parallel of north latitude agree with Bessel's curve better than they do with Clark's; this is the case all across the area on which Bessel's own work was done. But as soon as we get into the Volga Basin, the gravity line diverges from Bessel's curve and approaches that of Clark. The change comes due north of the Eurafrican meridional edge. The anomalies are at once removed if we assume that both ellipsoids are locally correct; that Bessel's curve is true for Europe, and Clark's correct for Asia; and that the two merge into one another north of the line of the Eurafrican tetrahedral edge.

On the tetrahedral theory there ought to be a projection north of this tetrahedral edge. And gravity determinations show a great deficiency in gravity in western Russia in an appropriate area along the Volga Basin. It is true that the figures have been queried. There is a natural tendency to query all facts that do not agree with theory, and the notes of interrogation in this case may illustrate that tendency. But on the view that there is an upward deformation of the earth in this area, the anomalous deficiency in gravity observations is at once explained.

It may be replied that the existence of a normal gravity attraction at Moscow negatives the assumption of a superficial deformation, but the relative excess of attraction there is possibly due to the outcrop of Palæozoic rocks, of greater density than the loose sediments of the Russian lowlands.

Passing from Russia to the area in North America, where the next tetrahedral corner should occur, there is another area of deficient gravity, which may also be due to that area being a tetrahedral elevation. The deficiency is explained by the assumption of vast subterranean blocks of very light material. But that explanation is prohibited in the Russian case, since, as Helmert has shown, the deviations of a plumb line from the vertical are inconsistent with the existence of such blocks. In reference to the North American case Helmert has remarked that the light subterranean blocks must descend for several kilometers; and Mendenhall has shown that no reasonable assumption will suffice to explain the facts.

It would be too much to claim that geodetical evidence at present available proves the tetrahedal theory, for accurate data are not yet available for a sufficient proportion of the earth to show whether the major deviations are based on a regular plan; but papers, such as that of Mr. E. D. Preston, show that geodesists are more inclined to regard the theory with favor. It is at least clear that geodesy does not disprove the hypothesis, and that some puzzling geodetic anomalies receive a simple solution if the theory be true.

GEOLOGY AND THE TETRAHEDRAL COIGNS AND EDGES.

Let us now turn to geology, to see if its evidence as to the past history of the world refutes or supports the theory.

The geological evidence ought to be of especial value, as we should expect it to determine the position of the tetrahedral coigns on the face of the earth.[1]

If the tetrahedral theory be true, the four tetrahedral coigns should be areas of unusual stability and strength. Comparison of the three meridional land belts shows that each of them begins in the north with a vast block of Archæan rocks. The Eurafrican zone, in longitude 20° E., begins with the block occupying Scandinavia, Finland, and Lapland, which Suess has termed the "Scandinavian schild." It is an area of great geological antiquity, which has long remained above sea level; bands of marine deposits of different ages sweep round it, but the block may never have been below sea level. It has unquestionably remained as a solid impassive block which has dominated the whole geological history of northern Europe. South of the Scandinavian coign are the transverse east and western chains of the Alps and the Atlas, with the Mediterranean trough between; and far to the south we have the old plateau of South Africa.

Let us now go 120° westward to the American zone. It begins with another block of old Archæan rocks, forming what Suess has called the "Canadian schild." It occupies Canada, Labrador, and most of Hudson Bay and Baffins Land, and underlies Greenland. Bands of marine deposits surround it, but it has perhaps never been itself below sea level; its geological age, at any rate, is enormous. South of the North American coign we have again a pair of east-west mountain chains, forming the highlands of Cuba and Venezuela, separated by the Caribbean trough. This zone also ends southward in an old plateau resting on Archæan rocks.

The third meridional zone repeats the same characters. It begins with a block of Archæan rocks, for which we may speak as the "Manchurian coign." South of this coign are the east and west ridges of Malaysia and the depressions parallel to them; and south of that, again, we have the Archæan plateau of Australia.

The three main land axes of the world have remarkable resemblances in structure, and they present three equidistant blocks of great stability at the three tetrahedral corners. We may therefore speak of the "schild" as the three northern coigns or corner stones of the earth.

[1] They were assigned to their geometrical positions by Green, and in the interesting recent tetrahedral volcanic map of M. Michel-Lévy.

The existence of these massive coigns[1] at the three tetrahedral corners has produced one point of divergence in the earth plan from the geometrical figure of the tetrahedron. The existence of three such broad massive blocks naturally strengthens the line between them; and, as we have seen, the main divide in the northern hemisphere runs from coign to coign. The tetrahedral edges would naturally be lines of weakness and of movement; but in the northern hemisphere the horizontal lines of yielding are deflected southward by the stability of the band supported by the earth's three northern coigns. Hence the great band of disturbances is subtropical, and runs from the Caribbean to the Mediterranean, across the Persian Gulf and the Malaysian Archipelago.

In the case of the vertical edges, however, the agreement in position, as well as direction, is exact. Precisely below the three corner blocks there are three lines of instability coinciding with the vertical tetrahedral edges. Below the Canadian coign there is the line of the Andes (longitude 75°), which according to some geologists is still undergoing elevation. Almost 120° east of the Andes, and below the Scandinavian coign, is the Erythrean rift-valley (mean longitude 40°), in which some of the earth movements are unquestionably of very recent date. Again, nearly 120° eastward, and due south of the Manchurian coign, is the recent line of movement represented by the eastern coast of Australia.

The main mountain system of the world corresponds, then, in direction or position, or in both, with the edges of the tetrahedron. The mountain lines run east and west in the Northern Hemisphere, and run meridionally in the Southern Hemisphere—that is, always parallel to the tetrahedral edges.

But it will be said there are three great exceptions, for the Ural Mountains, the Appalachians, and the Rocky Mountains are meridional instead of transverse, and that they therefore contradict the scheme. The contradiction is only apparent. The existing mountain ranges date from two main periods of mountain-building—the Upper Cænozoic and the Upper Paleozoic. The Upper Tertiary system includes the Alps, Andes, Himalaya, Pyrenees, Caucasus, and Atlas, etc. The Urals, Rocky Mountains, and Appalachians belong to the Upper Paleozoic system. Before we can say whether these chains confirm or refute the tetrahedral theory, we must determine the distribution of land and water at the time when they were made.

Now, we know that in Upper Paleozoic times one land fauna and flora ranged round the Southern Hemisphere from Australia to India, and thence to the Cape and South America. Instead of there having then been a continuous ocean belt separating triangular points of land, there was then a southern land belt, which was supported by three

[1] The suggestion of the word "coign" for "corner" I owe to Mr. L. Fletcher, to whom I am indebted for much helpful advice. The term is suitable, as it is used for a printer's wedge as well as for the corner stone of a house.

great equidistant corner stones, the Archæan blocks of South Africa, of Australia, and of Patagonia and the Patagonian platform.

What the South Pole was doing then is hidden by our deplorable ignorance of that area; but there is evidence that to the south of this southern land belt there was a cold, ice-laden sea.

Now let us consider the state of affairs in the arctic regions at the same period. At the present time the mollusca of the Bering Sea and North Atlantic belong to two essentially distinct faunas. But in Upper Paleozoic-Triassic times one fauna occupied both regions, and that fauna moreover extended uninterruptedly round the Northern Hemisphere, and apparently, along certain lines, extended some distance to the south. There was, in fact, a northern ocean belt, which apparently surrounded a cold arctic land. The distribution of land and water was then on the same plan as at present, but with land and water exactly reversed. There were two opposite interlocking belts of land and sea, the former based on three Archæan corner stones, the latter projecting toward the equator between three Archæan plateaux.

Thus the plan was the same as at present, but the conditions were reversed. This gives us the clue to the mountain chains of the same period. That, also, was a double system. There was a subtropical mountain girdle, the ruins of which we can trace right across the Old World from Eastern China to Western Europe, where it is cut off by the Atlantic slope. And projecting meridionally from that equatorial girdle, opposite the three coigns, we have three mountain ranges running along the meridional edges. These are the Ural Mountains (60° E.) north of the eastern continuation of the South African coign, the Appalachians (80° W.) north of the western part of the old Patagonian coign, and the old broken axis of Kamtschatka (160° E.) north of the coign of Australasia.

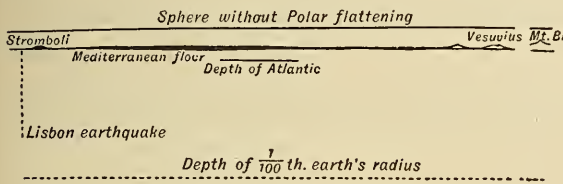
DEFORMATION AND RECOVERY.

Such a change in the position of the flattened faces is by no means improbable in the case of a revolving globe. In the case of a stationary body, a tetrahedral deformation once begun would be strengthened by every fresh contraction. But owing to the world's rotation, the tetrahedral collapse is steadily resisted, and confined within narrow limits. The deformation formed by one period of slow, quiet contraction may be lost on the restoration of equilibrium at an epoch of great crustal disturbance. When deformation begins again, in consequence of renewed contraction, the flattening may occur elsewhere.

This hypothesis of the alternation of periods of deformation with periods of spheroidal recovery is geologically useful, as it suggests an explanation of a certain periodicity in geological phenomena. For instance, the latter half of Paleozoic time may have been a time of slow tetrahedral collapse, culminating in an instability which led to the great mountain movements which closed the Paleozoic; then followed a quiet period of slow restoration of the spheroidal form, causing the series of marine "transgressions" which are the dominant feature of the geological history of the Mesozoic era.

VERTICAL RANGE OF DEFORMATION.

Reluctance to admit the possibility of such changes is reduced when we recollect how insignificant are the differences in level, when compared with the size of the earth. The use of exaggerated diagrams leads to unconscious magnification of the extent of the polar flattening, and of the difference between the continental summits and the oceanic



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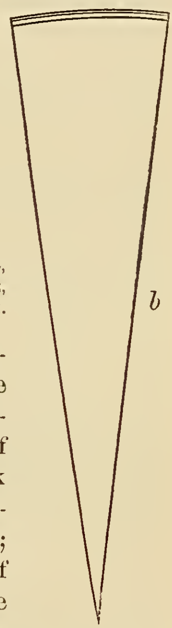

b

Fig. 7.

DIAGRAM OF RELATIVE EXTENT OF INEQUALITIES ON THE EARTH'S SURFACE. *a*, A TRUE SCALE CURVE OF PART OF EARTH'S SURFACE; *b*, SECTOR OF CIRCLE, SHOWING RELATIVE SIZE OF ZONE INCLUDED WITHIN *a* TO THAT OF THE EARTH.

depths. The study of large-scale maps has been authoritatively recommended. The examination of true-scale curves and outlines may help us to realize the actual conditions. The accompanying figure[1] shows a section of the earth's crust from Stromboli to Vesuvius. The thick black band represents the section across the Mediterranean; the line *a b* marks the depth of the Atlantic; the upper curve shows where the surface would be if there were no flattening. The lowest line marks the depth of one-hundredth of the earth's radius. The thickness of this zone in comparison with the size of the earth is shown on fig. 7, *b*, which is a sector of a circle, with the zone of *a* shown, reduced to its true relative size. The polar flattening is barely recognizable, and the difference between sea bottom and mountain summit is marked only by variations in the thickness of a line.

The diagram illustrates the insignificance of the deformations required; and that crustal disturbance occurs much deeper than the layer with which the tetrahedral theory is concerned is shown by the fact that the estimated center of origin of the Lisbon earthquake lies far below.

This diagram also serves to show that the amount of contraction in the earth necessary to allow tetrahedral deformation is very small.

[1] Based on Lingg's Erdprofil.

This is important because, as Lord Kelvin has shown, the amount of contraction allowable during the later stages of the earth's history is very limited. But geologists have the authority of Professor Darwin for accepting a certain amount of contraction. "A cooling celestial orb must contract by a perceptible fraction of its radius after it has consolidated," he tells us, and his considerations "only negative the hypothesis of any large contraction of the earth since the moon has existed."[1] And, unlike the contraction theory of the origin of mountain chains, the theory of the tetrahedral deformation of the lithosphere requires only a small amount of radial contraction.

Finally, it may be urged that even such deformation as the tetrahedral theory requires is impossible, since physicists have taught us that the earth is rigid. To this objection it is only necessary to reply that Lord Kelvin's rigidity arguments apply to the earth as a whole, and not to its crust; they deny the fluidity of the interior of the earth, and do not prohibit any local deformations of the exterior crust. The once prevalent astronomical belief in the absolute invariability of the earth's shape and in the absolute fixity of its axis of rotation (expressed, e. g., by Sir J. Herschel in 1862) no longer hinders progress. In fact, astronomers tell us that, instead of the absolute fixity of the pole, it now shifts its position to an appreciable extent under the influence of the movements of the atmosphere, the unequal melting of the polar ice, and by heavy falls of snow on the Siberian highlands. These movements of the pole are important, because they are taken to prove a certain elasticity in the earth. The movements demonstrated by actual observations are so far minute; but they at least allow geologists to say that, as such slight causes as those mentioned produce appreciable effects, more powerful causes acting for longer periods would work greater changes.

SUMMARY.

The object of the paper is to show that the old belief in a definite plan of the earth is justified, since the distribution of land and water on the globe has been determined by the tetrahedral arrangement of the elevations and depressions in the surface of the lithosphere.

This tetrahedral plan is shown by the existence of (1) a northern land belt, surrounding a northern ocean, and giving off three meridional land lines, which taper southward; (2) the southern ocean belt surrounding a south polar continent, and the three meridional oceans; (3) by the antipodal position of land and water; (4) by the course of the main watersheds and mountain chains.

It is held that this arrangement was not established in the earth's infancy, and therefore has to be attributed to some agency which has acted throughout geological history.

There are reasons for believing that a contracting sphere with a hard

[1] Phil. Trans., vol. 170, pp. 522, 523.

crust would undergo tetrahedral deformation, and the evidence of geodesy shows that the earth has been deformed from its spheroidal form. Its present figure may be defined as a geoid, which has been derived from a spheroid by irregular tetrahedroid deformation.

If such tetrahedral collapse be granted in the case of the earth, then the existing arrangement of oceans and continents receives a natural explanation.

The changes in the distribution of land and seas in the past may be explained as due to the conflict of two opposing forces, collapse caused by the earth's contraction producing deformations, which are reduced by the effects of the earth's rotation. Geological history affords evidence of the alteration of periods of tetrahedral collapse and spheroidal recovery.

The plan of the earth may, in short, be attributed to the continual foundering of the earth's external shell, owing to the unceasing shrinkage of its internal mass.

After the reading of the paper, the President said: In inviting the discussion of this paper, I believe that there are those here who have given some thought to the subject, and who will at least be inclined to tell us what their impressions are respecting the views set forth in Dr. Gregory's paper. I hope Sir John Murray for one will be disposed to give us the result of his impressions on the subject, and also Mr. Blanford.

I find there is a reluctance on the part of learned men to commit themselves to any opinions on a question which at present is in its infancy, and on which their views are not entirely settled. I think that some parts of the paper might have been discussed, and I can not help expressing, as I have done on other occasions, my regret at the loss we have sustained in our lamented friend General Walker, for there is no man who could have spoken with so much authority on one or two points, especially on the very slight differences that have occurred between astronomical observations and geodetic measurements. As Mr. Whittaker, the president of the Geological Society, is present, perhaps he would be disposed to address us.

Mr. WHITTAKER. I came to listen, not to speak. I found a little time ago that many gentlemen have come here after having the pleasure of seeing the proof. I am not one of those, and were I to speak, it would be without the advantage they have had; consequently they would have the pleasure of sitting upon me, and this goes against my feelings. I would offer one general remark—it is the satisfaction I feel with any paper of this sort that shows the interdependence of the various sciences, and how men who follow one branch of science should not have too much of that branch alone, but should see occasionally how it bears on others, and, on the other hand, how others bear on it. This calls in geologists, physicists, mathematicians, and many others, and it is too big to take up without a chance of going into the matter beforehand, and I decline to commit myself to details.

It is uncomfortable to think that, instead of being on a comfortable globe, as we had imagined, one is placed on a tetrahedron.

Mr. VAUGHAN CORNISH. The tetrahedral theory was described by Mr. Lowthian Green. When it was first promulgated it attracted very little attention, and no favorable attention; it was met almost with ridicule, and I think that it is, perhaps, not the smallest part of our indebtedness to Dr. Gregory that his great power of exposition has brought this theory again before the world, and though he has not yet secured for it a universal assent, he has at least secured a very careful consideration of what must, at all events, be considered a most substantial hypothesis. I think those who have followed carefully the able exposition of Dr. Gregory given to-night must admit that the tetrahedral convention, at all events, represents the observed distribution of land and water upon the surface of the globe. That distribution is essentially hemihedral, as they say in crystallography; the forms are not whole forms, but two half-forms interpenetrating, as we see in the oppositely directed wedges of the continents and oceans, and so far, I think, we shall most of us be prepared to go with Dr. Gregory. With regard to the physical causes which have produced such a deformation of the assumed spheroid, I think most of us will wish to reserve our judgment until mathematicians and physicists and followers of experimental science have tested it quantitively, and have seen whether these causes, which I suppose would go in the direction of producing tetrahedral, or tetrahedroid, deformation, are sufficient to produce the effects that Dr. Gregory has described.

The PRESIDENT. I think we shall all be agreed that this difficult subject, about which so few people seem inclined to give an opinion, has been set before us in a very clear and graphic manner and with great ability by our friend Dr. Gregory. I am sure you will all be ready to pass a vote of thanks for his most interesting paper. Although we are now almost for the first time realizing that the shape of the earth is not what it is said to be in the text-books, we may remember that the first person who supported the theory that the earth was the shape of a pegtop or a pear was Christopher Columbus, although he did not put the pointed end of the pear at the south pole, but near the region where the Venezuelan arbitration is going to take place. I now wish to ask you to pass a cordial vote of thanks to Dr. Gregory for his paper.

FUNAFUTI: THE STORY OF A CORAL ATOLL.[1]

By W. J. Sollas, M. A., LL. D., D. Sc., F. R. S.

(Professor of Geology and Paleontology in the University of Oxford).

By far the largest portion of the untrodden surface of our planet is formed by the floor of the Pacific Ocean. Submerged at an average depth of over 1,000 fathoms, it lies out of reach of the geologist's hammer for all time, and for the present at least is inaccessible to the diamond drill.[2] The geology of an almost entire hemisphere is thus the secret of the Pacific.

"It is the nature of a God," Bacon quaintly remarks, "to conceal a thing, it is the glory of a man to find it out," and certainly there would seem to be few secrets in Nature to which a clew has not somewhere been left for those who have virtue to discover it.

The mountainous margins of the ocean, still young and actively moving, may doubtless furnish us with many precious hints, but it is to the multitudinous islands, which in serried rows like the tops of submerged mountain chains extend across it, that we must turn in search of the true guiding thread.

Some of these islands, like New Zealand and New Caledonia, are in many important respects similar to our own, and seem to be the surviving fragments of a lost continent, which has fallen into ruins and sunk beneath the waves. Others, such as the Sandwich and Fiji islands, are also of a kind long since familiar to us, clusters of volcanic cones which, like Stromboli and Vulcano of the Mediterranean, rise from the depths of the sea.

In addition to these, however, there exist a third and strange kind of islands, restricted to the torrid zone, and known to the daring mariners of the Elizabethan period as "low" islands, a name well deserved, since few of them attain a greater elevation than many of the pebble beaches which fringe our own coasts; few indeed so great, the loftiest summits of most not exceeding the insignificant height of 10 feet. Owing to this fact they are scarcely visible till a ship is close upon them, and the

[1]Being the Friday evening discourse delivered before the British Association at Bristol, 1898. Printed in Natural Science, Edinburgh and London, Vol. XIV, No. 83.

[2]Profs. John Joly and Edgeworth David think it may be possible by suitable machinery to bore a hole in the floor of the deep sea.

first glimpse of a low island presents itself as a thin dark-green band, which separates the deep azure of the sky from the still deeper blue of the sea; with nearer approach a cream-colored streak inserts itself below the green and is instantly followed by a line of dazzling snowy white, which is soon recognized as the fringe of surf which marks the boundary of the sea. Sailing nearer, the streak of cream color becomes the island beach, and the zone of green resolves itself into a mass of luxuriant vegetation, over which the feathery crowns of the graceful cocoanut palms, towering to a height of 80 feet, wave indolently in the sea breeze.

As the details of this gracious scene, rising like an apparition from the deep, unfold before the eyes, one seems to gaze on some island of enchantment, and with the music of the surf thundering in one's ears one thinks of the Tritons sounding the loud conch, and half expects to "see old Proteus rising from the sea!"

If it be with surprise that we first make the acquaintance of these islands the feeling is in no degree abated with closer familiarity; from beginning to end their whole story is a chapter of surprises.

Mariners soon learned to dread the surf-beaten shores, for they could find no anchorage within a safe distance of the breakers, the sides of the island descending precipitously to great depths within a few hundred yards of the coast; and within this distance a reef of rough and rugged rocks forms the shelving floor of the sea. A bark once driven on to this heels over, with its deck facing the pitiless waves, and is swept clean from stem to stern.

Bristling with dangers on the outside, the island conceals within itself a spacious inner sea or lagoon, into which, through dangerous passages, a ship may make its way, and once there securely ride out the most destructive storm. The island thus differs from most others in being hollow in its midst; a mere rocky rim to a sea lake, which may be as much as 60 or even 100 miles across, and 60 fathoms deep, though 20 fathoms is more usual. From this feature the islands are known, not only as "low" islands, but as "lagoon" islands. The shores of the lagoon are bordered by a smooth, gently sloping beach of flesh-colored sand, over which the wavelets fall faintly; and palms and laurel-like shrubs growing down to the water's edge are reflected in its crystal margin.

When the voyager first set foot on this strange new land it was a fresh surprise to him to find it peopled. The inhabitants, usually graceful and prepossessing in appearance and amiable in manners, came timidly forth to welcome him, speaking a language full of soft vowel sounds, which has been aptly styled the Italian of the Pacific. In some cases, particularly when the natives were not red men but black, they showed less favor to strangers, and the island sometimes became the theater of bloody strife.

Besides man, whose presence is an additional problem of the islands, no other mammals are indigenous, their place being taken by various land crabs and spiders of many kinds.

An examination of the rocks of a low island reveals another singular feature; save for a few fragments of pumice, brought from distant volcanos by sea currents and cast by the waves upon the strand, they present us with but one kind of material, carbonate of lime, which has been extracted from solution in the sea and built up into a diversity of solid forms by the agency of organisms—plants and animals, of which the most conspicuous are corals. Thus but one kind of rock enters into the constitution of the island, and this is limestone; of granite, slate, sandstone, clay, such as we are familiar with at home, there is none; all is limestone, whatever you see!

The interest of this fact is enhanced by another. Repeated investigation has proved that the island is not merely a residuum, a mortuary of calcareous organisms, but that it is still alive and in active growth. A profusion of gaily tinted corals form reefs within the lagoon, and the whole of the shelving platform, which descends from the surf to a distance of 20 or 30 fathoms below the sea, is alive with them; this platform is indeed the true growing surface of the island.

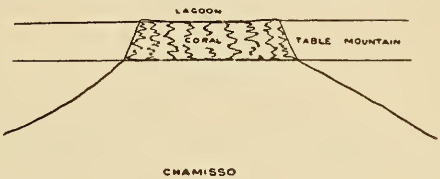

Fig. 1.

Corals, by reason of their considerable size and brilliant colors, first attract the attention of the observer, and hence, although numerous other kinds of creatures collaborate with the corals in the construction of the reef, these islands are known not only as "low" islands and "lagoon" islands, but also as "coral" islands, or more particularly as "coral atolls."

The remarkable discovery that coral atolls consist of the remains of animals and plants of precisely the same kinds as those which are at present adding to its substance excited general interest, and led to many fantastic speculations which need not now be recalled. The state of opinion at the beginning of this century may best be learned from the works of the poet naturalist, Chamisso, who may probably be more widely known as the author of Peter Schlemihl's wunderbare Geschichte (The Story of the Man who sold his Shadow) than as an investigator of coral reefs. In a description, which even in the light of the most recent research must still be pronounced excellent, Chamisso (fig. 1) speaks of atolls as table mountains which rise steeply from great depths. The summit of the table mountain is always under water, and is covered by the living reef which surrounds its margin as a broad platform and rises to the level of low tides. Sand banks resting on this form the dry land. Since, he observes, every particle of the atoll which lies within the reach of observation consists of coral, it is only just to conclude that the whole structure, including the table mountain, is formed of the same material. Not perhaps a strictly logical conclusion, yet, as events have proved, in the main correct.

Chamisso's opinion was not destined to remain long unchallenged, for two famous French naturalists—Quoy and Gaimard—asserted, as the result of their observations, that the coral rock of an atoll is only skin-deep—i. e., it forms, according to them, a mere superficial crust, not more than about 25 feet in thickness; the rest (Chamisso's "table mountain") being, on this view, of volcanic, or at all events of inorganic, origin.

Few of the arguments by which it was attempted to sustain this erroneous conclusion strike one as being very satisfactory, but they include one highly important observation, viz, that reef-building corals do not live at greater depths than 25 feet below the level of low tides. Subsequent inquiry, while fully confirming the existence of a limit, has at the same time extended it down to a depth of as many as 25 or perhaps even 40 fathoms. Yet, even with this modification, the unexpected discovery of Quoy and Gaimard seems to stand in flagrant contradiction to the views of Chamisso. If corals can not grow below a depth of 25 fathoms, how could they possibly have built up islands of over 100 fathoms in thickness?

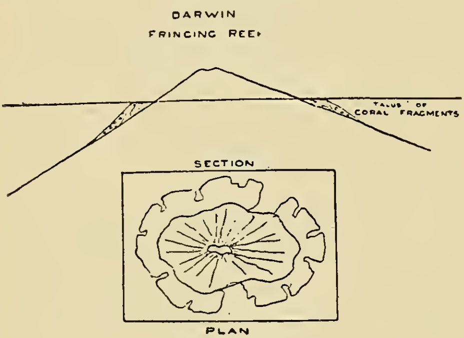

Fig. 2.
FIRST STAGE.

The answer to this question, as is well known, was given by Charles Darwin. If we admit the truth of both the apparently conflicting statements, it is obvious that the corals at the base of a reef 100 fathoms in thickness must have been situated within the limit of 25 fathoms at the time they were alive. But in order to bring them within this limit it is only necessary to suppose that the foundation on which they grew originally stood 75 fathoms nearer the sea level than it does now; or, in other words, that since the lower layers of the reef were alive and flourishing, the ground which supported them has sunk 75 fathoms deeper in the sea. No fact is better established than the rise and fall of islands situated in mid-ocean, and thus there is nothing antecedently improbable in this supposition. But once grant it, and Darwin's explanation of atolls naturally follows. Thus, let *a* be an island with its summit rising 100 fathoms above the sea; let its shores become peopled with corals, which extend seaward down to the limit of 25 fathoms, beyond which, as we admit, they can not proceed; a reef is thus started, which will continue to grow, rising upward till it reaches the level of low tides; when this is attained upward growth will cease, and the reef will begin to pass into decay, from the shore edge outward. So long as the island remains stationary, neither rising nor falling with respect to the sea level, this is practically all that will happen, and the final result is a reef not much exceeding 25 fathoms in thickness (fig. 2, first stage). But let us next suppose that the island begins slowly to sink into the sea, carrying the reef with it; the upward limit to the growth of the corals will be displaced; they will commence to flourish afresh, and the reef will continue to extend upward till the level of the low tides is once more encountered, and growth again arrested. This process of submergence and upward growth may of course be repeated indefinitely, and by the time the island has descended 50 fathoms below its original position, the reef will have acquired a corresponding thickness. In such a case the unfavorable conditions to the coral growth which prevail on the inner side of the reef, together with the retreating slope of the flanks of the island, will have led to the formation of a channel of sea water between the reef and the shore (fig. 2, second stage). Finally, let the submergence of the island continue till it is completely swallowed up by the sea, not a vestige of its summit remaining to mark its place; the upward growth of the corals, constantly proceeding, will bring them once more to the level of low tides, and the result will be the formation of a ring-shaped reef surrounding a central lagoon, or, in other words, of an atoll (fig. 2, third stage).

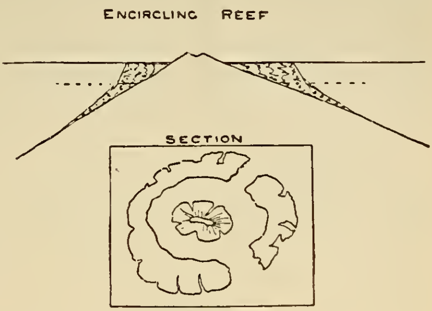

Fig. 2.
SECOND STAGE.

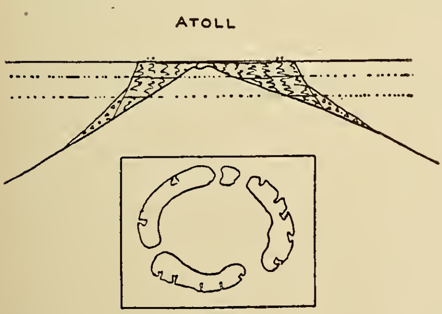

Fig. 2.
THIRD STAGE.

If this hypothetical scheme of the progress of events correspond to the facts, we may expect to find its various stages still represented among the numerous islands of the Pacific, and this, as Darwin endeavored to show, is clearly the case. The first stage, in which the reef is no more than 25 fathoms thick, and forms a selvage accurately following the margin of the land, is represented by that numerous class known as "fringing" reefs. The second, in which a comparatively thick reef surrounds an island with an intervening salt-water channel, is illustrated by another class, known as "encircling" or "barrier" reefs. In these, as we might expect, the form of the reef is only remotely related to the contour of the inclosed island, the valleys of which present that fiord-like character so suggestive of sunken land. The last stage is that of the atoll itself.

The excellence of Darwin's theory lies in this, that it explains all the essential features of an atoll on one simple assumption. It is inconsistent with no known fact, and as additional discoveries have been made it has not required to be supplemented by fresh hypotheses. It is not like a Gothic structure, supported by flying buttresses and other tours de force, but rather resembles some noble Italian tower, which rises from its base, straight, simple, and self-sufficing. It was no sooner given to the world than it commanded almost universal assent.

Nevertheless, it has never been without a rival. Even before Darwin published his celebrated work Ainsworth[1] had suggested a different explanation. He rightly pointed out that Quoy and Gaimard had not established a limit for all reef-building organisms, and that although certain corals, such as they had observed, might be restricted to shallow waters, there might yet be others capable of flourishing at greater depths. If so, these deep-water organisms might be engaged in laying the foundations of an atoll on which the shallower water forms might erect the superstructure (fig. 3). This suggestion seems to have fallen stillborn, but the notion of "laying the foundation" of an atoll was not destined to perish; it has been revived of late years by Sir John Murray, who, guided by his observations made when on board the *Challenger*, was led to suppose that the submerged summits of deeply sunken islands might be raised to within the limits of 25 fathoms, not by the upward growth of corals but by the incessant downward rain of minute organisms from the surface of the sea. The same agencies which were supposed to be spreading out a layer of chalky mud, or ooze, over the abyssal floor of the ocean were also imagined as engaged in piling a Pelion of mud on every submarine Ossa (fig. 4).

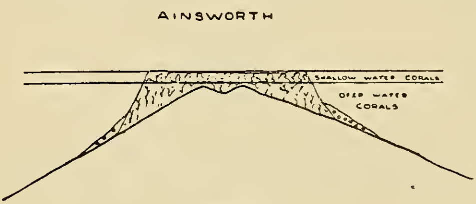

Fig. 3.

The publication of Sir John Murray's views was followed by a long controversy, in which Darwin's theory was subjected to a most searching criticism. An impartial summary of the arguments arrayed on both sides of the question is given by Professor Bonney in the last edition of Darwin's "Coral Reefs," and the general subject is treated

[1] G. W. Ainsworth. "Analysis of a voyage to the Pacific and Behring's Straits to cooperate with the polar expedition, performed in H. M. ship *Blossom*, under command of Capt. F. W. Beechey, R. N., in the years 1825, 1828."—Geog. Jour., Vol. I, 1831.

in the fullest manner by Langenbeck in a work entitled Die Theorieen ueber die Entstehung der Koralleninseln und Korallenriffe (Leipzig, 1890).

So far as the opposition to Darwin's views has come to count among its adherents a number of distinguished thinkers, it can only be regarded as having achieved a certain measure of success; a result not, to my thinking, to be wholly accounted for by the nature of the arguments employed. Possibly in this, as in similar cases, the ostensible objections are mere weapons of combat, while the real power has lain in the strong and subtle influence exercised by some general current of thought. Such a current is indicated in the tendency to a belief in what is spoken of as the permanence of continental areas and oceanic Basins.

According to Darwin, every atoll marks the site of a vanished island, but the atolls of the Pacific are so numerous that if one imagines all the islands they represent as summoned back from the "vasty deep" and restored to their original position above the sea, they will constitute a very considerable tract of land, and this situated in the very middle of the Pacific Ocean. Such a prospect could not fail to be unpleasing to those who believe in the immutability of the ocean.

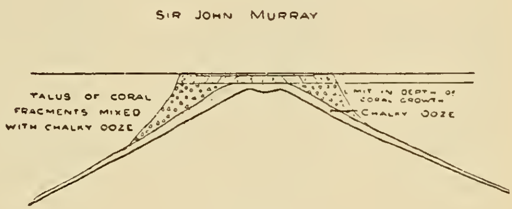

Fig. 4.

Of late years, however, this doctrine of "permanence" has begun to look a little threadbare. In a theoretical restoration of the distribution of land and sea during the Jurassic times, Neumayr has treated it with scant consideration, since he represents the North and South Atlantic, as well as the Indian Ocean, as then to a great extent occupied by land, and it is now very generally supposed that this land did not disappear to make way for existing seas till a comparatively late period in the history of the earth. Bold as Neumayr showed himself in the treatment of these oceans, he had not the temerity to take liberties with the Pacific. This he and geologists in general are disposed to regard as having maintained its existing features from a very early period. Of this ocean, and of this alone, would they exclaim, "Such as Creation's dawn beheld, thou rollest now."

Darwin's theory, as we have seen, does not hesitate to recall to existence land in the middle of even this ocean; this is its unforgivable offense—it lays sacrilegious hands on the Pacific, and thus attacks the doctrine of "permanence" in its stronghold.

While the recent controvesy on Darwin's theory was at its fiercest, and both sides seemed equally persuaded that the truth was theirs and must prevail, it occurred to me that a simple solution might be obtained by sinking a bore-hole through some well-characterized atoll, and thus obtaining specimens of the material of which it is composed, down to a depth considerably greater than that at which corals are supposed to build. How would this illustrate the question? Allow me to employ a homely illustration: buyers of cheese are not, I presume, naturally more suspicious than other persons engaged in trade, but they are unwilling to trust too much to mere outward appearance; they are not inclined to adopt the argument which commended itself to Chamisso in a parallel case, that because there is good cheese on the surface it must be good cheese all through; consequently, by means of a boring instrument, called a scoop, they make a hole through the cheese and bring out a core or cylindrical rod, in which the several strata of the material, if there be more than one, are displayed in their true thickness and natural position. The atoll is our cheese, which we propose to sample with a complicated kind of scoop called a diamond drill. This should provide us with a core in which the various layers of the coral reef should be faithfully represented. Should Darwin's theory prove correct, the core will contain the remains of reef-building corals as far down as the reef extends; if, on the other hand, Sir John Murray's explanation makes a nearer approach to the truth, layers of chalky ooze will be present at depths greater than that of the limit of coral growth (fig. 5).

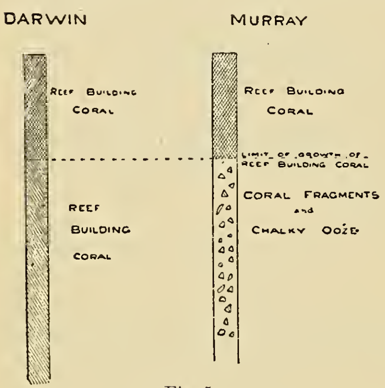

Fig. 5.

No one who has any notion of the extraordinary thoroughness with which Darwin attacked this as every other problem that he investigated, will be at all surprised to learn that the same solution had already occurred to him, and in a letter to A. Agassiz (May 5, 1881) he sighs for "some doubly rich millionaire, who would take it into his head to have borings made in some of the Pacific and Indian atolls, and bring home cores for slicing from a depth of 500 or 600 feet." As the wished-for millionaire did not appear to be forthcoming, it appeared to me that the boring might be achieved in another way, by a method very familiar to this association—I allude, of course, to a "committee." On approaching Professor Bonney with a suggestion to this effect he warmly entertained the proposal, and in 1891 a strong committee, including the most distinguished supporters and opponents of Darwin's theory, was formed, having for its object the investigation of an atoll by boring and other means.

Through the kind offices of Professor Stuart, of Sydney, we obtained from the government of New South Wales the offer of the free loan of a diamond drill. Our next step was to select an island for investigation. This was rendered an easy task through the invaluable assistance afforded by Admiral Wharton, whose extensive knowledge of coral reefs renders him the most formidable of Darwin's opponents. At his suggestion our choice fell on Funafuti, one of the Ellice or Lagoon Islands, situated in the middle of the Pacific (latitude 8½° S.), seven days' sail northward of Fiji. No better selection could possibly have been made. Not only is Funafuti an atoll of unexceptional character itself, but it belongs to a family of atolls all of equally unexceptional character; and these again to a system which includes the Gilbert and Marshall islands, all of them excellent atolls. So far as these are all distinguished by the same characters, whatever may be found true of Funafuti will apply to all the rest.

The labors of the committee of the British Association were then taken over by a committee of the Royal Society, at whose request the admiralty generously assigned to our assistance the *Penguin*, one of Her Majesty's gunboats, commanded by Captain Field, and stationed in the Pacific for exploring purposes. The Royal Society furnished funds to defray expenses, and the direction of the expedition was placed in my hands; two volunteers, Mr. Gardiner, of Cambridge, and Mr. Hedley, of Sydney, were, with my permission, to accompany me.

We joined the *Penguin* and left Sydney on May 1, 1896, taking with us a boring party which had been selected for the work by Mr. Slee, the Government inspector of mines and drills. Its foreman, Ayles, had acquired great reputation in the colony by his success in conducting boring operations of exceptional difficulty. On May 21, after three weeks' voyage, we heard the welcome cry "Land ho!" and Funafuti was seen on the horizon. The ship was steered for the southern entrance; this was safely made, and we steamed into the noble lagoon. Flying fish spurted from under our bows, and zigzagged in their darting flight around us; here and there in the midst of the blue waters green and purple shallows marked the site of growing coral patches. On the starboard side lay the beautiful island of Funafuti proper, its pale sands ablaze in the light of the tropical sun, its groves of palms cool with a refreshing green. A boat put off from the beach manned by a crew of copper-colored natives, their black hair crowned with wreaths of gardenia and hibiscus flowers. They were soon swarming over our sides, bringing with them the solitary white trader of the island, who safely piloted us to anchor within a mile of the shore. Captain Field and a party immediately landed, and we went at once to pay our respects to the king, who, notwithstanding the narrow limits of his realm and the smallness of his nation, which numbers only some 240 souls, we found to be every inch a king. His Majesty received us with gracious dignity, led us into his palace, one of the few stone huts on the island, and seated us by his side on the daïs, which consisted of packing cases. The chief men sat round the walls on the floor, and smiling damsels, with large black eyes, ivory white teeth, and long black tresses floating loose, shyly presented us with freshly opened cocoanuts to drink, a civility which as inevitably attends a call in Funafuti as the afternoon cup of tea at home. We told our errand, and received permission to choose a site for boring operations. We then requested that a house should be built for us, and were promised that this should be done for the modest sum of £6. The reception ended, we proceeded to choose a site for the boring and for landing gear, and marked out the plan of our house; it was to measure 15 by 20 feet. We were anxious to have the building of this put in hand at once, and were assured that it should be ready for us by the afternoon of the next day. The east is supposed to be more fertile in promise than performance, and our expectation was that we should see this house when we did see it. Judge, therefore, of our surprise when on passing the same spot the day after we found a substantial structure already standing there. It had grown up like Aladdin's palace in a single night. The whole population had been employed on the work; the men had cut down trees and shaped them into poles, sunk these in the ground, and bound them together into a solid framework; the children had been set to gather palm leaves from the forest, and the women had woven these into mats, which were used to form both the walls and thatch of our dwelling. The result was an excellent house which served all our needs, protecting us from sun and storm during our residence of nearly three months. Not a nail was driven in its construction, all the joints being firmly made with cocoanut cord.

After contemplating the work with great satisfaction I left for a stroll, and returning an hour after was aghast to find our new house surrounded with smoke and flames. To my great relief it turned out that the conflagration proceeded from the surrounding bush, which the thoughtful natives had purposely set alight to prevent its taking fire by accident.

The work of landing gear and erecting machinery was set about vigorously. The crew of the *Penguin* toiled all day heroically in the burning sun, refreshing themselves at sunset in swimming matches with the natives. Progress was so rapid that by June 3, not quite a fortnight after landing, the boring party were already at work. So far all our plans had been carried out with expedition and success, and, since "things done well and with a care" are said to "exempt themselves from fear," we may now safely leave our miners industriously boring while we take a walk across the island. Standing on the shore of the lagoon near the site of our boring, it is just possible to catch a glimpse of the palms on the opposite side, some ten miles away. The beach slopes so gently, that although the tide falls only about 5 feet, it leaves a wide expanse of sand uncovered. This is a perfect warren of shore crabs (*Calappa*), which scurry along like blown thistle down and vanish into holes with mysterious suddenness. It is at night that these are most active, when they dig deep burrows in the sand, casting up conical hillocks at the entrance nearly a foot high, which give the beach the appearance of a miniature encampment. The sand is the famous "coral" sand; but on picking up a handful for nearer inspection we are surprised to find that it contains scarcely any coral; and, so far from consisting of detrital material, it is almost entirely composed of the shells of Foraminifera, two species predominating, *Tinoporus baculatus* and *Orbitolites complanata*. From specimens collected on other atolls by the late Professor Moseley, and preserved in the University Museum at Oxford, it would appear that the sand at Funafuti is by no means singular in this respect, and the term "coral" sand is only another instance of the "lucus a non."

The lagoon beach ends in a tiny cliff about a foot in height,[1] to the very edge of which sparse turf and vegetation of a larger growth extends. The land to which this cliff is boundary consists chiefly of small fragments of coral and shells of Foraminifera. It rises a little, so as to attain a maximum height of 3 or 4 feet above high-water mark. In breadth it varies considerably, and where broadest the native village stands, with the church, large enough to contain the whole population, all churchgoers, the school, mission house, and palace. A row of graves, made tomb like with slabs of coral, runs down the middle of the main street. The whole of this sandy flat is covered with rich forest growth, cocoanut palms in all stages, from the young plant just sprouting from the shell to the ancient of the groves, 80 feet in height, bearing heavy clusters of ripe fruit beneath its crown of feathery fronds; pandanus, with its strange adventitious roots and truculent sword-shaped leaves, broken in the middle; the laurel-like Nono (*Morinda citrifolia*) and the "Nya" tree (*Pemphis*), with its heavy stem of hard red wood and delicate foliage. Ferns abound, and some brightly colored flowering plants; an *Abutilon*, which puts forth fresh blossoms day by day, and a handsome bean, which trails through the forest, bearing large heart-shaped leaves and heavy racemes of lilac flowers.

The great robber crab (*Birgus*), which feeds on cocoanuts and pandanus fruit, is at home here, and may be seen climbing the cocoa palms by night. Other land crabs scramble through the fallen palm leaves which thickly strew the ground. Many of these are of the hermit kind, and one of them has a curious habit of croaking like a frog when captured. But no part of the island is free from land crabs. Like rats and mice, they are the universal scavengers. They undermined our house, attacked our tinned provisions, and one could not sit down to eat a cocoanut without some of these weird creatures gathering round to pick up the fallen crumbs.

As we continue our passage across the sand the scene rapidly, even

[1] This applies to that part of the islet on which our house was built. In some places more considerable cliffs are met with, e. g., on one of the northern islets of Funafuti called Amatupu, where a conglomerate of coral pebbles form steep faces some 6 feet or more in height.

abruptly, changes its aspect. The place of the forest, so rich and varied, is taken by a grotesque growth of "Nya" trees, whose stubborn, contorted trunks, strangely at variance with their dainty foliage, bar the way. Struggling through these, one enters upon a savage plain "horrid" with rugged fragments of blackened coral and cumbered here and there with huge bowlders of coral rock some tons in weight.[1] At low water this desolate region is dry and burns in the sun, but as the tide rises sea water oozes up through holes in the ground and covers it with shallow pools. Few animals live in this desert. Spiders, that infest the "Nya" trees, and mosquitoes, that lie greedily in wait by day as well as night, are the chief that I bear in mind. Proceeding lengthwise along this plain, which lies in the middle of the island, it broadens out and passes into a muddy swamp planted by the natives with taro, a delicious substitute for potatoes, and bananas, which one still reflects upon with pleasure. Their fruit was our chief luxury, and we willingly paid for it at the somewhat exorbitant price of 4 fathoms of calico a bunch.

Farther on, beyond the plantation, the depression becomes still wider, forming an extensive flat, partly margined by mangrove trees and *Hibiscus*. This was known to us as the mangrove swamp. It is an interesting corner of the island. The floor represents the upper surface of a deal coral reef, composed partly of great masses of *Porites*. Their flattened summits, standing some 8 or 10 inches above the floor, give them the appearance of a row of stepping-stones and mark what was the level of low tide at the time the reef was living.[2] Radiating from these blocks as from a nucleus are vertical plates of the "blue coral" (*Heliopora coerulea*), which extend outward, branching as they go, for a distance of 3 yards or more. Overlapping the reef lies a layer of consolidated coral breccia. It has suffered much from erosion by the sea and bounds the inner side of the depression in cliffs 3 or 4 feet in height. A sheet of clear, green water covers the swamp at high tide, converting it into a shallow lake, which, as the tide falls, empties itself through deep holes in the floor into subterranean passages, which freely communicate with the outer sea. The northern end of this depression is closed by coral breccia and overgrown with mangroves, but farther on it recommences and extends through the remainder of the island, almost as far as its northernmost extremity, forming a discontinuous narrow trough bordered by steep cliffs. This trough and the depression to which it belongs owes its origin in some degree to solution by sea water.

We have deviated from our walk across the island to follow the course

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[1] One of these measured 6 feet by 5 feet by 4 feet.

[2] The last episode in the history of the island appears to have been a slight elevation of some 4 or 5 feet; at least I was led to this conclusion from evidence furnished by the "dead reef" of the mangrove swamp, by the "sea stacks" or pinnacles of coral rag of the tidal platform, and by the steep cliffs which in some of the islets border the lagoon.

of its central depression. Let us now return and resume our traverse. The blackened fragments of coral, resembling nothing so much as the clinkers of lava which cumber the slopes of Etna, continue seaward, and are loosely piled to form a gently rising ascent—so loosely piled that they often topple over at a touch and afford very uncertain or even dangerous foothold.

Walking circumspectly, therefore, up the slope, we soon reach the summit of a long ridge and find ourselves looking toward the Andes, some thousands of miles away over the broad waters of the Pacific Ocean. We stand on the top of the "storm beach," the loftiest region of our island, at the imposing altitude of 10 or even 15 feet, according to the state of the tide. On the seaward face the storm beach descends somewhat rapidly, and near its foot a sheet of hard consolidated coral rag emerges from under it, to form a gently sloping platform, over which the tide ebbs and flows. In places this tidal platform rises in low cliffs, ridges, and pinnacles[1] of fantastic shape, but for the most part it presents itself as a sheet of limestone, smoothed and polished by the wearing action of the waves. For about 50 yards from its seaward edge it is hollowed into a broad, shallow depression, not deep enough to be called a channel, and finally swells into a narrow rounded rim formed by the growth of a pink-colored calcareous seaweed known as *Melobesia*. Beyond this rim, which projects above the sea at low tide, lies the growing surface of the reef, which is constantly submerged, so that under no circumstances are the corals, which thickly cover it at any time, exposed to the air.

Deep chasms gash the edge of the tidal platform, the continuation inland of the lanes of clear sea which wander through the growing reef; in these chasms a few corals may generally be found, their polypes sometimes brilliantly colored and in full expansion.

The calcareous alga, previously alluded to as *Melobesia*, forms the lips of these chasms, and by its luxuriant growth may more or less completely roof them over, generally leaving one or more apertures, which act as blowholes.

The ocean side of the reef is one of the pleasantest parts of the island; a cool breeze almost always blows there; and, under the welcome shelter of the palms and pandanus which crowd the summit of the storm beach, one may watch the beautiful and impressive spectacle below; the ocean, of a deep majolica blue, rolls inward in majestic waves, which suddenly grow gigantic as they approach the shore, towering in a wall of water above the reef, and then spring with a furious roar into a confusion of white foam, which seethes about the madder-tinted margin of *Melobesia*, rushes through the chasms of the tidal platform, and often spouts up through the blowholes with sudden and explosive violence, like a kind of marine geysers. It is only on calm days that the extreme margin of the reef can be approached with

[1] See note 1, p. 400.

safety. Such is the violence of the breakers that the tidal platform presents the appearance of an almost lifeless desert; a few green and brown seaweeds, little fish darting in the pools, occasional sea snails with dense shells, and a few hermit crabs heavily armored, are all that is seen at first glance. All the inhabitants of the tidal platform seem to stand in dread of the sea; even the active shore crabs (*Grapsus*) are afraid of it, and only venture in when inspired by their greater terror of the human form; even then they cling tenaciously with their many legs close to the sides of the rocky shore, and sidle off to land directly they fancy the enemy's back is turned.

The observer who trusted to first impressions, and judged the platform by its outer aspect, would fall into grievous error; it is by no means so dead as it seems. On breaking off a fragment with a hammer a new world of life is revealed; the rock is tunneled through and through, as closely as it can be mined, by a variety of animals, which have taken to an underground life as a protection against the sea; worms, shellfish, crabs, sea squirts, and barnacles are to be found in these subterranean dwellings; they constitute a specialized fauna of marine troglodytes, which might, if we wished to add to the burden of nomenclature, be designated the "Cryptone."

After this brief description of the superficial features of the atoll we may next endeavor to trace the history of that part of it which rises above the sea and properly constitutes the land. The sheet of hard coral rock which we mentioned as cropping out beneath the storm beach can be traced into the interior of the island, where it forms the floor of the central depression; and again to the lagoon side, where it emerges to form the floor of the lagoon and in many places the beach or as well even a low line of cliffs. In the little islet of Pava, north of Funafuti, it is seen to extend continuously from one side of the land to the other—from the ocean to the lagoon.

We may, therefore, fairly conclude that this sheet of rock forms the solid base on which the land above it rests. It is composed mainly of slabs of coral, lying not quite horizontally, but overlapping like the tiles of a roof, with a slight inclination toward the ocean side of the reef.

These fragments have evidently been derived from the outer zone of growing coral. Before the land as it now exists was formed the waves were incessantly engaged in tearing off fragments from the coral zone and driving them across the reef into the lagoon till a thick sheet of débris was the result. This became consolidated as it formed, partly by the growth of incrusting calcareous algæ, and now forms the solid floor of the island.

Masses of broken corals, torn up and driven inland by the breakers, continued to accumulate after the formation of the floor; and thus that great pile of coral clinkers which forms the storm beach has been and is still being built up.

On the other side the wavelets of the lagoon have washed up smaller fragments of coral and foraminiferal shells, and thus the strip of land which borders the lagoon and on which the village of Funafuti stands has been produced.

The middle of the island—the great central depression including the taro ground and the mangrove swamp—is the remains of the original solid platform left exposed between the storm beach on the one hand and the lagoon land on the other. Thus all that portion of Funafuti which stands above high tide has been cast up from the ocean and the lagoon, and this beautiful island, like another Aphrodite, has been born with the foam from the waves of the sea.

If this be the true history of the island, how then did it acquire its inhabitants? Did they climb upward like the corals as the island was submerged or did they arrive as flotsam and jetsam of the sea? As regards the natives there can be but one answer—they came by boat. In former days the Polynesians possessed excellent seagoing craft, in which they were accustomed to make long voyages, steering by the stars and other signs in the sky. They well knew how to preserve food by drying, and thus had no difficulty in provisioning for a cruise. The routes they followed in passing from island to island are gradually becoming known to us and have been indicated on a chart by Professor Haddon. Considering the remarkable similarity of language which characterizes all Polynesia, from New Zealand on the south to the Sandwich Isles on the north, there can be little doubt that the migrations of these peoples must have taken place comparatively recently, and judging from tradition one might conjecture within the last seven or eight hundred years.

Thus, long before the illustrious townsman of this city, John Cabot, had anticipated Columbus in his famous voyage to America, these navigators, whom we libel with the name of savages, were venturing on equally arduous explorations with still more imperfect means at their command. It was not often, however, that long voyages of over a thousand miles were made of set purpose; too frequently they were the result of accident, as when frail canoes were overtaken by a sudden storm and driven at the mercy of the winds, sometimes to perish miserably, sometimes by good hap to land on undiscovered shores.

The Funafuti people seem some of them to have entered the island with intent; others are mere waifs and strays cast away by shipwreck on the reef. The prevailing stock is Samoan, with an admixture of Tongan. In bygone times the Tongans used to make periodical descents upon the island, after the fashion of the Vikings in early English history. The Tongans, however, came not only to kill, but to eat their foes, a proceeding not wholly unintelligible among a people who knew absolutely of no other kind of meat. In justice to the copper-colored races of Polynesia I hasten to add that cannibalism was seldom the custom of this folk; wherever it is met with it may be taken to indicate the influence of black blood. So far as we know cannibals are almost always black people.

Returning to the boring party, which we left busily engaged. For nearly three weeks they worked by shifts continuously night and day, but at the end of that time, when the bore hole was only 105 feet deep, their most arduous efforts failed to advance it farther. The difficulties opposed by the nature of the ground—a mixture of flowing sand and obdurate bowlders—were such that neither the good will of the workmen nor the ingenuity of Ayles, the foreman, could contend against them, and there was no alternative but to abandon the undertaking.

Thinking that there might be a better prospect of success on the ocean side of the reef, we determined to make a fresh attempt there, and in two days, without the help of wheels and in a country without roads, we succeeded in transporting the bulk of our 25 tons of machinery across the island to a fresh site. The new boring commenced in hard rock and at first deepened rapidly. Before long, however, it entered a mixture of sand and bowlders similar to that we had previously encountered, and after attaining a depth of 72 feet further progress became impossible. We left the island on July 30, and on reaching Fiji had the mortification to learn that we had passed on the way a ship coming to our assistance with a fresh supply of machinery, which our friends in Sydney had promptly dispatched on hearing of our difficulties.

Our attempt to penetrate the reef had proved a failure, but it was not wholly without result. It had revealed the nature of the material with which any subsequent attempts at boring would have to contend, and it had added one more surprise to the history of atolls, for no one had suspected that for a depth of over 100 feet the island would be found to consist of more sand than coral, or in other words, that the organisms which play the chief part in the construction of a coral reef are not corals, but Foraminifera!

The expedition had other objects in view besides boring. The next in importance was the investigation of the atoll by sounding. This was accomplished with complete success by Captain Field. Other atolls had been sounded before, but never before had an atoll been sounded with such accuracy and completeness as was Funafuti on this occasion. The form of the floor of the lagoon was made more exactly known than that of most lakes in the British Isles. The slopes of the flanks of the atoll were determined in four different directions, approximately at right angles to each other and running about north, south, east, and west. A study of these enables us to frame a clear picture of the general form of the atoll. It is a conical mountain with an oval base situated at a depth of about 2,000 fathoms, measuring 30 miles in length by 28 in breadth. It rises at first with a very gentle slope, but gradually grows steeper as it ascends (fig. 6) till at a depth of 400 or 500 fathoms it begins to present precipitous faces, and above 130 to 140 fathoms is crowned by the almost vertical cliffs of Chamisso's "table mountain," which, as he rightly divined, is of a similar nature from base to summit. All this is coral reef; how much more may be so it is impossible in the present state of our knowledge to say.

The general feeling of disappointment with which our failure to bore through the reef was received was fully shared by our friends in Sydney. Determined not to be put off with a first rebuff, they promptly commenced to make arrangements for a second attempt, and last year (1897) an expedition again left Sydney for Funafuti, this time under the direction of Prof. Edgeworth David, of the University of Sydney. Under his leadership the boring proved a complete success. The reef was penetrated to a depth of 697 feet, or 116 fathoms. Thus Darwin's wish has now been more than satisfied. The core brought up was sent over to this country and is now in the hands of Professor Judd for investigation. Till he has completed his report it would be premature to enter into details, but from a general examination, made without the aid of the microscope, I think I may fairly venture to say this much: That the material brought up from the boring, and of which the reef is

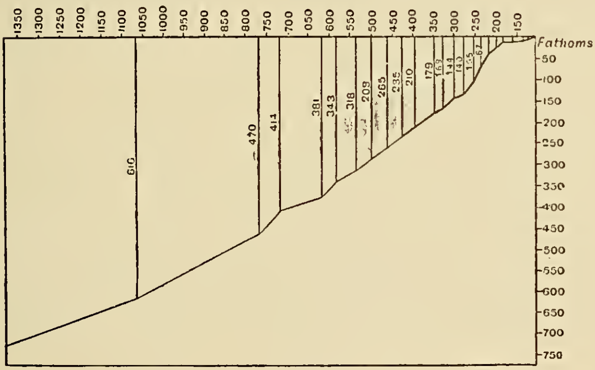

Fig. 6.

composed, presents much the same general character throughout and so far supports Darwin's theory; that layers of chalky ooze, such as on Sir John Murray's hypothesis we might have expected to find in the lower parts, are conspicuously absent; and finally that it presents no trace of volcanic material.

On whatever side judgment may ultimately be given in this question, the thanks of the scientific world must undoubtedly be conceded to Sir John Murray for having disturbed a decided opinion from its slumber, for having awakened a fresh interest in Darwin's theory, and in thus leading to renewed investigation, which is both adding to our knowledge and suggesting fresh inquiry.

The sand showing little trace of consolidation, which was noticed in our boring down to 100 feet, is maintained in Professor David's boring down to about 100 fathoms, and it is not a little remarkable that material so loosely aggregated should be able to sustain itself in slopes of as much as 80°, such as characterize the flanks of Funafuti. It is important, however, to observe that none of the borings yet made have been sunk through the true growing substance of the atoll. They have commenced on the lagoon side of the true coral reef, and the deeper they have descended the more remote they have become from the ocean flanks. The possibility exists, and should not be overlooked, that a great part of the material passed through in the bore holes represents deposits of the lagoon and of the fragmentary débris driven toward it by the breakers.

It will be observed that Professor David's bore hole does not traverse the whole thickness of the table mountain; judging from the soundings, it would have to descend 20 or 30 fathoms deeper to do this, and it would seem likely that the material obtained from this last 20 or 30 fathoms might surpass in interest all the rest. Our friends in Sydney fully appreciate this, and are so bent on probing this question to the utmost that they have already dispatched, at great pecuniary risk, an expedition to make a third attempt on Funafuti, and this time to carry the bore hole right through the table mountain.

The boring party is at this moment at work on the island, and before many weeks have elapsed we may expect to receive tidings of their success. A great stride will then have been taken toward a final determination of the long-standing controversy on the origin of atolls.[1]

We eagerly await the result, which will inform us whether these central oceanic islands are ancient remains of land which have plunged beneath the sea and are renewing their youth, or whether they are among the latest products of our planet, aspiring mountains which have scarcely yet succeeded in their struggle upward to the light of day; whether they are, as has been said, "a garland laid by the hand of Nature on the tomb of a sunken island," or whether they may not be a wreath of victory crowning a youthful summit on its first conquest of the main.

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[1] The critical point has been passed. (See Nat. Sci. XIII, p. 362.) According to the news from Funafuti (September 6) the boring attained a depth of 987 feet, or 147 feet below the base of the steepest cliff. The material passed through was coral limestone. It is of interest to observe that, soon after passing the bottom of Professor David's bore hole, loose unconsolidated deposits ceased to be encountered, and the drill passed with comparative facility through a hard limestone containing numerous well-preserved corals. A crux of all theories of atolls is the lagoon. On Darwin's theory its explanation follows naturally from the fundamental assumption. Sir John Murray has to supplement his hypothesis by a separate explanation, and proposes to account for the lagoon by solution. In this connection the success which has attended an attempt of the present expedition to bore into the bed of the lagoon is most welcome. The boring was made from the deck of H. M. S. *Porpoise*, commanded by Captain Sturdee, and after passing through 101 feet of water sank 144 feet into the deposits of the floor. The first 80 feet were found to consist of the calcareous alga *Halimeda* mixed with shells; the remaining 64 feet of the same material, mingled with coral gravel. This alga is universally distributed over the floor of the lagoon, as proved by an examination of the material obtained by Captain Field in sounding, and since it contains a certain percentage of magnesium carbonate we are led to expect that the formation of dolomite will be found to stand in some connection with the transformation of lagoon deposits.

OCEANOGRAPHY.[1]

By M. J. THOULET.

A new science has lately made its appearance and is beginning to be recognized. To be exact, it is not absolutely new; it is nearly two centuries old in its well-defined aim, its methods of investigation, its known laws, the indication of possible discoveries which remain to be accomplished; in a word, in its individuality as a didactic science, but until very lately it was the object of individual research only, and as it was studied but by a few specialists it remained almost unknown to the public.

This science is oceanography. Its purpose is to ascertain the phenomena which are going on in the depths of that immense mass of water which covers more than three-fourths of our globe, to consider them, explain them, discover and formulate the laws that govern them on the surface and at the bottom of those abysses which were once supposed to be unfathomable—at the time when people believed in the unfathomable. To-day oceanography is progressing with giant strides. All maritime nations contribute to its development, no less from the theoretical point of view, for its great benefit to the human mind, whose right and duty it is to seek to know all things, than from the practical point of view of the material advantages to be derived from it; for the contest between man and nature, growing always more severe, makes it imperative that no force be left unproductive. France established oceanography. She made important discoveries and then stopping, left the care of continuing the work to others, forgetting even those of her children whose attainments, unnoticed by her, were elsewhere seized upon and utilized. Now that foreigners have made an advance which it is impossible to ignore, she seems to be aroused to a regret for the time and territory lost. She is certainly in a position to promptly regain both if she desires it.

We intend to explain of what oceanography consists, to show its direct relation with other sciences, its theoretical and practical utility; we shall give a short history of its progress from its beginning until the time when it became a complete whole; a clear and systematic exposition

[1] Translated from the Revue des Deux Mondes, Vol. CXLVI, pp. 897–921.

of facts carefully considered and elucidated. We shall say a few words concerning what has been done in this line of thought by different nations, with the character which their peculiar temperament, the conditions of their past and of their present have given to their work. In fact, just as the acts of each man, physical as well as moral, are marked with the special imprint of his personality so in the domain of science every race stamps its work, the product of its collective intelligence, with an impress peculiar to it, which constitutes the very essence of its genius.

I.

Oceanography is the study of the sea. Static oceanography deals with salt water considered independently of the movements which are manifested in it; it treats successively of the topography of the ocean beds and of their formation, their lithology. It analyzes the waters, their composition and their influence on the nature of the depths, their numerous physical properties, the effect on them caused by changes of temperature, their density, their compressibility, the way in which light is diffused throughout the superposed strata, and the different optical phenomena. The ice of the polar region offers subject matter for a chapter on the effect of cold on the sea.

In dynamic oceanography the ocean is studied in motion. We study the waves, which move the surface under the influence of the wind, and the currents, which, like the network of our arteries and veins, traverse its mass to a certain depth, and result from the simultaneous actions of heat, evaporation, the topography of the sea bottom, the geographic configuration of the surrounding continents, the climate, the force of the winds; in a word, from the total of exterior causes which, whatever they may be, all exert some influence and in turn are influenced—a constantly recurring cycle of change whose cessation would bring instant death to our planet as the last beat of the human heart terminates the life of the body. Dynamic oceanography also includes the study of the tides, whose rhythmic movements accord with those of the stars, and the examination of those processes by which the débris of the continents, swept off by winds or washed away by rivers, reach the great common reservoir, are diffused throughout its waters, descend in a shower to the very lowest depths, and there accumulate to form rocks like the greater part of those which we find now on our continents and which formed the bottom of the oceans of former ages. It deals with the phenomena that result from the contact between sea and land, seeks out the laws which control the formation of deltas or of the bars which extend across the mouths of rivers, the filling up of estuaries, the way in which waves and currents shape the contours of the shores, dunes, lagoons, and those madreporic formations—atolls and coral islands—conquests of organic life over inorganic matter, of the infinitely small, the zoophyte, over the infinitely powerful, the ocean.

Oceanography has to do then, directly or indirectly, with a multitude of sciences and, more than any other, with geology. The present is at the same time the key of the past and of the future, especially in natural history. Man, in his investigations, works from the known to the unknown, from what he can see with his eyes, touch with his hands, measure with his instruments, to that of which he can perceive only the results; from phenomena present before him to those which were accomplished thousands of centuries ago. For a long time geology advanced in a rut out of which oceanography has forced it perhaps a little against its inclination. Old people and old sciences have their habits and a dislike to change, but old sciences, more fortunate than man, can grow young again.

Rocks are of igneous or metamorphic and of sedimentary origin. The former are the object of the researches of a special science, petrography, which studies their intimate nature and all the different branches of knowledge which relate to eruptive phenomena. Stratigraphy deals with rocks of aqueous formation, and, as the genesis of these is intimately connected with the order of their superposition, stratigraphists, in their investigations, consider together the constitution and the order of the sedimentary strata. Now, since these strata have been found beneath the water, nothing is more fitted to make their genesis clear than observation of the manner in which at the present time rocks are being formed on the bottom of our oceans. This task, to which it applies itself with ardor, is the duty of oceanography. When the particular character of the formations on the coasts or in the depth of the sea is known, when careful observation and exact measurement of actual phenomena shall have taught, for example, the necessary relation between the form and dimensions of a grain of sand and the exact velocity of the current which has transported it and affected its shape—angular when supported by force of the water, worn and rounded when simply rolled along the bottom among other grains; as soon as the presence, recognized quantitatively, of a fixed proportion of clay in the midst of a sandy deposit shall allow us, by means of physical and mechanical laws, to determine whether this deposit was formed in calm or agitated water; as soon as numerous measurements, repeated in different parts of the ocean, shall have established the generality of these relations—that is to say, made laws for them—we shall be ready to reconstruct the past. It will be sufficient to find the same characteristics in an old deposit to be able to call established relations to our aid. We may affirm that the point where the deposit was formed was at such and such a depth in the ocean, at such a distance from the shore. If, later, other sciences bring forward their cooperation and point out new relations, all the details will, one after another, appear. We shall then ascertain the size and form of the Silurian, the Carboniferous or the Cretaceous Sea, the force of its waves, its salinity, the temperature of its waters, the intensity and direction of its currents, its flora and its fauna. Thus, having for foundation only a single grain of sand observed beneath the microscope and which, through oceanography, shall have recounted all the events at which it has assisted, after centuries upon centuries the edifice will appear firm, solid, in its complete magnificence. Do not think that this is a scientific dream, as full of uncertainty as of charm. These deductions have the absolute and unquestionable precision of mathematics. After so many unexpected discoveries, our epoch leaves it no longer in doubt that the greatest poets are sometimes the scientists.

The laws of meteorology present an important practical interest because they lead up to the forecasting of the weather. There is no need to dwell upon the profit humanity may derive from such a discovery. How many misfortunes will be averted for the agriculturist! Navigation will feel no less benefit if it can know in advance the regions of calm, of contrary or favorable winds. How many voyages will be shortened, how many lives saved! We can judge of this from cyclones. Formerly the terror of sailors, since their laws have been known they have been utilized to expedite voyages. The subjugated hurricane works for the sailor, and when ordered to bring the ship more quickly into port the docile tempest obeys and thus averts the dangers of the route. Who among our forefathers would have dared to formulate such a dream, realized, nevertheless, through the work of Bridet? Now the laws of the aerial ocean and of the liquid ocean are the same, although more complicated for the first than for the second. They should consequently be studied synthetically on the sea and applied afterward to the atmosphere, with such modifications as are made necessary by the great difference in the mobility of the two fluids. The rational introduction to meteorology is oceanography. Steam has greatly modified and simplified the former conditions of navigation, and to-day steamers progress almost in a straight line despite wind and sea. However, the sailing vessel is not as dead as some may believe. As a result of the mutual interactions, so delicate, so changeable, of economic conditions, of the high price of coal, of the large space occupied by the machinery and the store of fuel, of the higher salary of mechanics, and for still other causes, many nations are returning to sailing vessels. Americans in particular possess clippers of great speed, which carry freight at less charges than do steamships. The study of the phenomena of the ocean has lost none of its practical utility to navigation and it has become indispensable for the elucidation of a multitude of points. Marine currents are elucidated by meteorology, because of the influence which regular winds have upon the flow of the waters. They control the course of floating ice fields. The dangers to boats off the banks of Newfoundland are well known. To this place come the icebergs which have broken off from the glaciers of Greenland, and have been carried down Baffin's Bay by the Labrador current to melt away at contact with the Gulf Stream. The accumulation of the resulting débris of rocks forms the banks of Newfoundland.

These ice fields are of particular interest because of the fear they inspire, because of the shoals formed by their melting, and particularly because the chilling occasioned by their contact with an atmosphere warmer and more saturated with moisture, gives rise to heavy fogs. Hundreds of disasters would be avoided, enormous economy in the transportation of merchandise would be effected if we could succeed in understanding and foreseeing these phenomena. The admirable pilot charts published every month by the Hydrographic Bureau at Washington seek to solve the problem empirically, noting to what latitude the ice fields descend each year, observing their number, and establishing the probabilities concerning them according to the average of numerous observations. Fogs due to analogous causes—that is to say, to marine currents—are frequent in the northern or even the temperate region, on the North Sea, the English Channel, and on the Atlantic coasts of England and France. Everywhere they are the terror of sailors; ships move in them bewildered, advancing at the risk of running ashore or colliding with another vessel, while if they remain stationary they are in danger of being themselves struck, and in any case they lose time, that precious commodity whose price rises higher every day. The ability to foresee their presence, or if overtaken by them to find the course and follow it with certainty, would be the immediate consequence of the perfecting of oceanography.

Some attempts at this have been crowned with success. The position of a ship in the ocean is usually determined by the aid of astronomical coordinates. According to the observed position of a heavenly body, star or sun, the observer calculates his own position on the surface of the waves. Knowing where he is and where he is going, nothing is easier for him than to follow his course. But the indispensable condition is to see the star; this the fog renders impossible. This impossibility is the cause of most shipwrecks. However, the position can be otherwise determined. If we have a so-called bathymetric chart, plainly indicating by means of contour lines the depth of the water at each point, and another chart drawn up after a series of soundings and of preliminary analyses showing in the same part of the sea the changing nature of the bottom, here sand and there mud of one kind or another and there rocks, by a single cast of the lead a vessel lost in the midst of the ocean can determine her position. The depth of the sounding will confine the observation to the area for which the bathymetric chart gives this depth. If, moreover, care has been taken to fit the sounding lead with some means by which a sample of the bottom may be brought up, the area covered by this kind of bottom may be looked up on the lithologic chart, and, combining this information with the preceding, one will be able to ascertain his position almost exactly. Excellent applications of this method have been made in France by Commander de Roujoux and by Captain Trudelle for landfalls in different localities, along the Channel, at the entrance to New York, Havre, Brest, and the very dangerous approaches to Cape Guardafui. Two oceanographic coordinates have taken the place of the astronomical coordinates. The vessel, having lost her sight, makes use of feeling. To draw up bathymetrical and lithological charts is one of the principal objects of oceanography.

Oceanography has to maritime fisheries a relation still more important, if that is possible, than to geology, meteorology, and navigation, for this industry is related closely to the very life of nations. In France we have more than 86,000 marine fishermen, while more than 200,000 people derive, directly or indirectly, their means of existence from fishing; as, for instance, the men and women employed in the canning factories.

There are very many marine animals of which man makes use either as food, such as fishes, crustaceans, certain mollusks such as oysters and mussels, or to gratify his needs of all sorts, as sponges, pearls, coral, the great cetaceans, as whales or cachalots, and seals, from which he obtains oil and skin. No being escapes from the influence of the surroundings in the midst of which he lives and which govern his material existence as well as his manners, his morals, and his intellectual faculties. Nowhere are these restrictions more strikingly evident than in the water, probably because they are found there in a state of the greatest simplification or, to be more exact, the least complication. The laws of oceanography are, then, the rational basis for the conduct of fisheries, which have become methodical and consequently scientific, and pisciculture is a kind of agriculture of the sea.

In the harmony between a being and his environment, three cases present themselves: If the harmony is perfect, the being, finding the utmost satisfaction for his needs, develops and multiplies; if it is only partial, the being who suffers it becomes rare; if, finally, the harmony is absent, the being will disappear by flight if he possesses, like an animal, the power of motion, or by death if, like a plant, he is condemned to remain in one place. The living creature thus indicates in three ways the condition of his surroundings—by his presence, his rarity, or his absence. Dredgings made even in great depths show in a striking way the extreme specialization in the distribution of the animal species, among which some are evidently more sensitive to the environment, others less so. Each special group conforms to corresponding, special, exterior conditions, physical, chemical, or mechanical, and in this way the animal, vegetable, and, to a certain degree, even the mineral becomes an instrument of measurement, roughly graduated, it is true, because while abundance or absence are relatively easy to recognize, nothing is more vague and less determinable than degrees of rarity. A fish found in a certain locality indicates that the water there possesses a depth, a temperature, a certain limited range of salinity, a special kind of bottom and currents of calculable speed. All these details are implied in the presence or absence of this fish. Fishing is a problem which consists in knowing beforehand whether in such a place at such and such a time the fish will be abundant, rare, or absent. Other nations have fully recognized that the study of fisheries is, above everything, the study of the relations existing between the marine environment and the animal; that is to say, a question of zoology whose first basis is knowledge of the environment, which is a question of oceanography. They have put the principle in practice in their laboratories and in their official administrations, working out in detail the oceanography of a region before devoting themselves to zoological researches there. It is to be wished that this practice were more generally followed. It is a common sense law, but it is only too true that such are the slowest in making themselves known. Every improvement is simplification, and the men who cry unceasingly for simplicity are as if appalled when they come upon it unawares.

But if the presence or absence of a fish is so difficult to determine except by long and expensive trials, it is not so with the condition of the environment, which can be estimated and even recorded in figures, by means of instruments; temperature by the thermometer, density and salinity by the areometer, depth by the sounding line, the nature of the bottom by a lithological or chemical analysis. The instrument offers the advantage of having a perfect graduation, recording a sufficient number of degrees and consequently great delicacy of indication. On the other hand, it has the inconvenience of recording but one of the conditions of the surrounding of which the living creature records the whole. However, we must not forget that the purpose of science is, briefly, to discover what is above all others the most essential influence, and besides that if a single instrument is not sufficient, there is nothing to prevent our having recourse to many in succession. It would cost the fisher less time and trouble to measure the temperature and then, if it is necessary, the transparency and even the density in a certain region, then according to the results obtained set to work fishing with great probabilities of success, or to immediately leave the ground, than to cast his line and nets into the water, throwing his bait away haphazard, to learn finally only after a prolonged trial that the fish will or will not bite. Prof. H. Mohn, of Christiania, formerly head of the splendid Norwegian oceanographic expedition of the Vöringen, in 1876, found out[1] that at the Loffoten Islands the cod remained always in a bed of water between 4° and 5° in temperature (39° to 41° F.). According to his instructions a Government vessel, commanded by Lieut. G. Gade, went to ascertain the position in depth of this bed and to verify the scientific previsions. The success of this examination was perfect, and now Norwegian fishermen use the thermometer as a fishing

[1] H. Mohn. The Temperature of the Sea, and the Fish in the Loffoten. Christiania, 1889.

apparatus. They seek a stratum having a temperature of 4° or 5°, the depth being variable not only in the same locality but also in the same region from time to time, and as soon as they find it they cast their lines and fish with certainty. The example is pertinent. It was furnished by an eminent scientist; it has received and still receives, every season, the sanction of practice and affords actual benefit to fishers. How eminently desirable it is that such a study should be made on the Newfoundland Banks or in Iceland, I mean in a serious way, by a competent person, and, as was done by the Norwegians, on board a vessel specially adapted for this research.

Other experiments no less interesting have been made in the laboratory of pisciculture in Flödevig. The Norwegians live by the sea; they are obliged to cultivate it, and, in fact, they declare that they have succeeded in restocking it with cod. Their processes are now being applied at Newfoundland by the English. It has been observed that the spawn of the cod must be raised in water of a certain temperature and density. If the water is too dense the young fish are not sufficiently strong to overcome its resistance and seek food on the bottom; if it is too light they easily reach the bottom, but have difficulty in holding themselves there, while if it is within the required limits of density, the animal, able to move at liberty, finds entire satisfaction of his needs and develops rapidly until, having reached his full strength, he ceases to be sensitive to the slight variations in his surroundings and can nourish himself in the sea where he is given his liberty. Breeding is carried on at Flödevig under perfectly systematic and scientific conditions, with the greatest benefit to the industry.

In the laboratory at Dildo, near St. John, Newfoundland, where similar restocking is carried on, the director, Mr. Nielsen,[1] discovered that the water in the breeding ponds for the male and female cod intended for reproduction must have a temperature from 4 to 7 degrees and that young cod, living well in water at zero, will die as soon as the temperature falls only half of a degree.

By reason of the development of science and general progress, war has become so difficult and frightful in its consequences for the two adversaries, neither of whom can ever be really victorious, that it is almost impossible between nations that are about equal in the scale of civilization. If nations wish to live and not be overwhelmed, peacefully but completely, by other peoples, their competitors in the terrible struggle for existence, they must use to their best advantage the riches of their territory. If agriculture, now scientific, obtains profit from the work of scientists who have transformed it from the collection of empirical recipes into a positive science; if we seek by knowledge of the soil, by suitable alternations of the crops, by appropriate fertilization to procure the best results from a piece of land, to make it produce a maximum of yield, we should do the same with the sea. We

[1] Dr. Nielsen, Annual Report, 1893, pp. 21 and 22.

must admit that we are in this respect undeniably inferior to other nations. Still plunged in lamentable ignorance and regardless of the information obtained by careful scientific experiments, we ravage our coasts, and statistics show that the fishing industry is incapable of furnishing daily bread to those who practice it at the cost of so much trouble, fatigue, and danger. We profit by the sea as savages profit by the earth, when, according to the famous simile, finding a fruit tree in the forest they cut it down to gather its fruit. We have no complete and detailed map, not even a mediocre one, of the sea bottom, nor have we any exact ideas of the variations in temperature, in density, in salinity, along our coasts; we have not calculated the amount of sediment deposited by any of our great rivers; we are ignorant to what depth currents are felt and, except for a very small number of localities, as to their direction on the surface; we have no idea of their variations in intensity at different periods of the year. It is only too easy to add to this list of the data which we now lack. However full of good intention the measures of the administration may be, they are fruitless if they have not the intervention of authority to sanction the application of the measures approved by science. How can we be astonished by the poverty of our fishers and the fatal consequences which can not fail to affect the country? Fish are an important item in the economies of nations. According to statistics now somewhat old but rather increased than diminished by time, the world captures and consumes annually 2,000,000,000 francs worth of fish.

The industry of laying submarine telegraphs depends on oceanography to the same extent that the construction of railroads or canals depends on topography and continental geology. Perhaps the dependance of the telegraphs is even greater. The railroad and the cable follow the contour of the soil; both, for analogous reasons, must avoid too irregular ground, and the nature of the bottom is of the utmost importance. On certain bottoms swept by currents, as on the Wyville Thomson reef to the north of Scotland, the cable, subject to continual vibrations against the pebbles or frayed by their unceasing friction as they are washed about by the movement of the waves, wears out and breaks, however solid its envelope may be. At other times, on volcanic bottoms, as near Greece, for example, or in the Malay Archipelago, the cable may be stretched by displacement of the ground, causing changes in the level which break it.

The landing of the cables is no less important. Rocks are always very dangerous if they are situated in the zone of action of waves and tides. While in the open sea the land has every chance of being uniform, near the coast it often becomes irregular. It presents sudden declivities or deep hollows, reefs, straight crevasses bounded by almost perpendicular walls, such as M. Pruvot has recently discovered, not in some unknown corner of the Pacific or the South Sea, but in the

Gulf of Lyon, some miles from the little port of Banyuls near Port-Vendres. A cable laid across such a valley is sure to break, and if the perfect knowledge of the topography of the region does not make the cause of the accident clear, we may be tempted to strengthen its envelope, that is to make it heavier and consequently more certainly provoke a subsequent rupture. It is not without reason that the English companies have in their service a fleet of telegraphic vessels intended for these studies alone, carrying a special technical staff, unceasingly employed in working on oceanography. They evidently guard against making known the obtained results, and are no more to be blamed for their secrecy than would be those contractors for building railroads who, provided with detailed maps of a region over which they have been ordered to lay a road, should conceal their documents, acquired laboriously and at great expense, from the engineers charged with overlooking their work and with paying them, and who on their side must, therefore, remain in ignorance of the topography and geology of the country. England holds the monopoly in the construction of submarine lines. France possesses only a small number, and, even of these, the larger part were built by the English. It is not enough to possess colonies beyond the ocean; it is necessary to be in direct communication with them. That we are at the mercy of foreigners for our telegraphic communications, the events of Siam and Madagascar furnish proofs painful to record.

II.

Oceanography is a science which applies to the natural phenomena of the sea, the precise methods of the exact sciences, mathematics, mechanics, physics, and chemistry.

It is a science of experimentation, of measurements, working by analysis and by synthesis toward the final end of learning the present history, and consequently the past and future history, of the earth, because all science which discovers and states laws is a prevision. Oceanography is thus a branch of geology, and since the soils stratified—that is to say, deposited—in the midst of the sea, formed by it, enter largely into that portion of the earth's crust which is directly accessible to our investigations, we would be authorized to claim oceanography as the most important branch of geology. It is ludicrous to hear arguments on the Silurian, the Devonian, or the Carboniferous oceans, now millions of years old, to hear discussions concerning their shores, their waters, or their currents, while we still know so little of our own ocean of to-day, on whose surface our vessels sail, into which we plunge our bodies, over whose immense circumference we are free to cast our gaze, with whose waters we moisten our lips if we wish, whose waves sing their monotonous and majestic harmony in our ears, of which we can take full possession by all our senses.

The foregoing considerations enable us to appreciate in its principal characteristics the method employed in oceanography. The application of experiment and of measurement seems at first particularly difficult, if not impossible. It is neither. As regards the ocean, it is certain that the phenomena apparent there are more than complicated—they are terrible; and their grandeur apparently puts them far beyond the power of man. It would be of no use to approach the study directly. However, even the forces of the sea are forced to yield to experimentation on condition that we proceed gradually, studying first lakes—oceans in miniature, governed by laws similar, although less complicated, and consequently more easy to discover and verify. In oceanography a phenomenon must pass through three phases of study: It is established on the ocean, found in lesser degree on lakes, and studied by synthesis in the laboratory. Thus its law is discovered. Then, taking the inverse order, it is ascertained whether the law is verified on lakes, and at last we come back to the ocean. We observe whether the law holds good there, and in case of modifications (which usually occur) we seek their causes and consider what new elements have become involved which were absent, or perchance ineffective, on lakes or in the laboratory. The study is now complete and definite, since, if necessary, we may return to the laboratory, where, rich in the suggestions which have arisen from our new survey, fortified by a first approximation; we can arrive at a greater precision, thanks to a new synthesis established by new experiments. We work from the known to the unknown and from the simple to the complex, retracing our steps if necessary.

The objection has been made to the experimental method that phenomena in miniature such as we can produce in the laboratory are not identical with natural phenomena, since they represent them on a reduced scale. This reasoning rests on a misunderstanding; everything goes to prove the contrary. Why should a heavy body left unsupported descend into the sea in any different manner than it descends in a tube some meters in height filled with salt water? If the changes are brought about by the duration of the fall, the depth, the pressure of the layers of water, and other circumstances, these changes can be studied and estimated by means of separate experiments. It is the usual method of resolving a natural phenomenon by means of curves of a single equation with multiple variables. Admitting that in certain cases a single experiment in the laboratory is insufficient to reproduce the phenomenon, yet a series of experiments, each of which would be performed to make clear the action of one of the components of the problem, would represent it in its entirety. When, for example, we have measured in a tube 3 or 4 meters long the duration of the fall of globigerina in sea water, we evidently do not learn all the laws of such a fall in the sea. It would be otherwise if, after having made the experiment with ordinary pressure, we repeat it with pressure more and more considerable, then with different temperatures, and each time note the variations resulting from the influence of each of these variables. Suppose that we have experimented carefully and tested separately everything that reason, ordinary common sense, points out as playing a part in the descent of dust particles through the ocean. If we then verify, first in a lake, then in the ocean, each of the laws discovered in the laboratory; if we determine that in the latter they are simply multiplied by a number, the constant coefficient of increase, we shall refute the critics. If there is a disagreement, we are apprised of the influence of some variable of which we have not taken account; and it will be necessary, after having discovered it, to experiment on it in turn. When all the work is finished we shall have the proof that, while with a single experiment taken separately we can not analyze nature, with the entire series we can do so.

It is thus that we should consider oceanography, which, proceeding upon the plan of not studying the past until the present is well understood, has introduced the experimental method into all that part of geology relative to sedimentary deposits. It is thus properly a branch of this science.

When a traveler, overcome by the long and painful ascent of a mountain, finally reaches the summit, he finds it pleasant to him to sit on a rock and, while recovering from his fatigue, contemplate the plain which he has crossed, the river whose windings he has followed and which at this moment spreads out below him, and also the difficult, even dangerous, ground, the sand, the marshes, over which he has come with great exertion. Certain stages of the journey had seemed to him short, others had appeared very long, and now he calculates what they are in reality. He distinguishes each error that he has committed. If, then, turning round, he looks down the other slope of the mountain, he sees what road he must follow to arrive surely and promptly at the end of his journey, visible afar in the mist of the horizon. What he has done gives him courage to complete his task; the victory he has won over fatigue and obstacles is the warrant of his victory over the fatigues and difficulties of the future. He gathers new ardor, strength, and hope. Is not this traveler like the man of science in his journey, laborious and painful as is all travail, toward the distant truth which, in his short life, he is certain never to reach? At least he will approach it at the cost of many mistakes. He has opened up the path, and those who follow behind him, profiting by his labor, will surpass him. They will go on farther and yet farther, obedient to that thirst for truth with which God has endowed every human soul as a mark of its divine origin and future immortality.

It is necessary to know the history of a science to understand those works with which it deals and to foresee those which remain for it to accomplish. Let us now show in the history of oceanography how its development has been influenced by different sciences and how it has influenced in its turn numerous others and their applications. It is the same in every stage of the intellectual improvement of humanity. We realize with difficulty the momentum (giving to this word the meaning usually assigned to it by physicists) of a new idea, which leads in its train a veritable world and pushes another on before it. This is, perhaps, the explanation of the difficulty with which a new idea overcomes the opposition it meets from a crowd of people and things that feel that after having lived they are about to disappear. Nothing consents to die, and routine is only an instinct of preservation.

Oceanography came in without noise. The human mind naturally seeks causes for that which is seen, or to better recollect them after they are discovered or even surmised, because of its very weakness it hastens to deduce laws for them. The first navigators were not impelled by curiosity which would have been incapable of fortifying their hearts with the triple armor necessary for facing the sea; they were moved by selfish interest and by want. The Phœnicians ventured upon the blue waves of the Mediterranean to provide themselves with slaves and metals to sell elsewhere and because it was impossible for them to live confined on the narrow strip of land bounded by the chain of mountains which separated them from hostile hordes. The Scandinavian pirates, on their light "drakkars" with curved prows crowned with the head of a dragon or bird of prey, fled through the rough waves and tempests of the North Sea from a vast but unfruitful fatherland where their time, which it was useless to spend in agriculture or in the tranquil arts of peace, was given up to social struggles, to perpetual combat, to victories and, consequently, to defeats, after which the vanquished was forced to submit to the vengeance or oppression of the vanquisher. Thus, not many years ago, the Polynesian, driven by famine from his island which had become too densely populated, flew in his pirogue with high sails of matting over the great swell of the Pacific. To all these voyagers the sea, despite its terrors, became a refuge. He who feels himself separated only by a few planks from moving abysses, where his gaze sees nothing when, profiting by the hollows in the waves, he tries to penetrate their depths, realizes that terrible forces too vast to be conquered by any human power surround and rule him, and that brute force avails nothing; it is necessary to call to his aid skill and science. All sailors are scientists, some more so, some less, according to their abilities, in order to elucidate the phenomena going on around them, of which they would be the plaything if they did not set to work in some measure to predict them in order to draw from them, first, security and then profit. How useful it would be to know the probable regions of calms and of storms, the strength and the direction of the currents, and the mutual connection of the phenomena of the earth, the heavens, and the waters, so that when one of them has been examined the other may be foreseen, and if it is to be feared, conquered. The more humanity advanced the more the sum of its known facts increased, the more indispensable it became to coordinate them, the more legend and empiricism became transformed into science.

Thus antiquity and the middle ages passed; thus these "sea rovers," as Michelet calls them, advanced—Icelanders, Arabs, Dieppois, and Basques. We can not admit that the sailors who then plowed the Atlantic, the Indian Ocean, and the seas of China could remain indifferent to the favorable or unfavorable circumstances whose advantages or dangers were the more worthy of attention since their ships were smaller and less capable of resistance than are the enormous vessels of the present day propelled by steam. It is only through skill that the weak are victorious. When the Norsemen about the year 1000 went from Norway to Içeland, from Iceland to Greenland, and from Greenland to that Vinland which five centuries later was to become America, they left in the places which they there discovered names which showed that natural phenomena had markedly attracted their attention; Straumsoe, the island of currents; Straumsfjorde, the bay of currents; Straumness, the cape of currents.

Suddenly, about the middle of the fifteenth century, the world experienced a great disturbance. The Renaissance began to make its influence felt throughout all Europe. There was a universal awakening of curiosity, of science, of ambition, of life; that is to say, of desire of enjoyment and of gold. There are such periods of fermentation in the lives of individuals as in those of nations. Their primary wants were satisfied, they desired more. The earth was divided among different races, each race divided into peoples, the peoples into provinces, the provinces into villages, hamlets, castles, all hostile to one another, warring, fighting, massacring, and being massacred. The least painful road for peaceful or for adventurous spirits, impatient with an ambition difficult to satisfy in the old countries, was now the sea. All nations launched out upon the waters. Some, Venetians, Genoese, sought riches and found them, others sought riches and rule over vast countries. The sea gave glory and fortune, asking in exchange only boldness, and valiant spirits of all nations, Portuguese, Spanish, Italians, French, English, and a little later Dutch, embarked on vessels. Columbus discovered America anew, a discovery that was not the result of chance. Admitting that he had not received formal assurance of its existence, he foresaw it, guided by his observations and oceanographic information, marred and distorted, but nevertheless collected and transmitted from mouth to mouth. At Porto Santo he had handled a piece of carved wood thrown upon the shore by the currents and during former voyages he had remarked that the western shores of Norway, Scotland, and Ireland were strewn with pieces of wood of unknown species brought by the waves from an unknown land. He, too, sought this land and found it.

When he reached it and, wishing to broaden the field of his discoveries, navigated that sea which was later to be called the Caribbean

Sea and the Gulf of Mexico, he never relaxed his observation of the movement of the waters. At the "Serpent's Mouth," near the Gulf of Paria, he saw that the current turned to the west; he recognized this again on the coast of Honduras. Grouping the results of his experiments he formulated an hypothesis and declared that the sea in its advance followed the firmament from east to west. The true father of oceanography is the Gulf Stream. It seems as if men had invented the science solely to explain this current, which even to-day is the most studied and best known of the phenomena of the ocean. For many years all the sailing expeditions from Spain radiated around Hispaniola and Cuba. Ocampo sailed all around the latter island. In 1513 Ponce de Leon, having for pilot Anton de Alaminos (who had been pilot for Columbus in his last voyage), set out in search of the Fountain of Youth in Florida, and his vessel passed with difficulty through the waters whose current set with great force toward the north. A little later Diego Columbus, the son of the admiral, gathered together his data, combined them, and as Pierre Martyr d'Angleria recounts, asserted the continuity of this river of the ocean and that of the continent which checks it on the west and turns it back in a contrary direction. Scientific data appeared. Anton de Alaminos, after he had accompanied Cordova, then Grijalva, around Yucatan and the Gulf of Mexico, became chief pilot of Cortez when he went to seize the empire of Montezuma, and when the conqueror feared to be stopped by the jealousies and intrigues of his enemies in Cuba and Madrid, in order to baffle them, he charged his pilot to return in all haste to Spain and carry to the court dispatches, and particularly presents. Alaminos was the first to make use of his observations. To arrive more promptly he took the longer route, and leaving Vera Cruz turned his vessel toward the north of Cuba and the straits of Florida. We have here the three successive phases—the oceanographic discovery, its formulation and use for deductions, and lastly the putting it in practice.

All seas were traversed. Bartholomeu Dias discovered the Cape of Tempests; Vasco da Gama doubled it and entered the Indian Sea; Magellan and his Basque pilot, Sebastian del Cano, made the first voyage around the world; the Cabots, Jacques Cartier, Francis Drake, Hudson, Willoughby, and many others went from all coasts seeking empires or a more direct route by the north of America to India and China. Navigation and geography gave rise to the first observations relative to the sea. Each people, seeing, with reason, a competitor in every other people, took the greatest care to guard the secret of its discoveries. The Carthaginian boat, pursued by a more powerful Roman vessel, did not hesitate to cast itself on the coast and to break upon the rocks rather than indicate the way to the country of tin. Vasco da Gama in his war vessel massacred the crew and passengers of the poor Arabian boutre which he found laden with pilgrims in the Indian Sea. However, despite all efforts, the facts which could be made use of were slowly divulged, spread, and reached the ears of scientists, who arranged them and disseminated them with the power that had arisen with the recent invention of the art of printing.

Interest and curiosity awoke in proportion as knowledge developed. The era of geographic discoveries passed because there were no more empires to conquer. Competition died out and there began a period during which a passion for natural history seized the nations, while individuals bore proudly the title of naturalists. Travelers visited unknown islands and continents, gazed with wonder at the curiosities of these lands, and wished to describe them in detail. They did not at first consider whether or not this would be of any practical advantage, but confined themselves to the knowledge that these things existed, that the forms of plants and of animals were unusual, and this was sufficient to interest them. It was the epoch of enthusiasm. From the middle of the last century until about the middle of the present the world was enamored of social ideas, of political ideas, of art, literature, science, and even geography. They were taken by everything. Like children in infancy, they rejoiced almost without suspecting it in the supreme happiness of possessing a faith—often, indeed, two or three rather than one. Setting out boldly to discover the Utopia of their dreams, so long known and yet always so new and so full of charm, they traversed the oceans. Great voyages were made. In 1772 Cook went to Tahiti, accompanied by the naturalist Forster, to observe the transit of Venus. In 1815 the Russian Kotzebue went round the world on the *Rurik*, with the naturalist Chamisso; in 1826 the future Admiral Fitzroy took Darwin aboard his ship, the *Beagle;* Bougainville on the *Boudeuse*, De Freycinet on the *Uranie* in 1827, Vaillant on the *Bonite* in 1836, and still others studied the natural history of all climates and brought back large collections. There was the same enterprise on land as on sea. Victor Jacquemont went to India overflowing with ardor, intoxicated with love of science at the aspect of the wonders and grandeur of nature. Those who were born half a century ago look back on a childhood and youth brightened by the last gleams of these emotions. We did not then have encyclopedias of scientific romances, the quintessence of human knowledge contained in 500 pages as the meat of an entire ox is concentrated into one small pot, and we were, for want of more or less substantial nourishment, forced to feed our minds with fancies. We began with the history of Sindbad the Sailor, the old man of the sea, the valley of emeralds and of rubies, over which the roc hovered, beating the air with great outspread wings. We went on with the library of voyages—Cook, Dampier, Carteret, Lapérouse, the reminiscenses of Jacques Arago, the blind man, and the adorable letters of Victor Jacquemont. With our books of pictures—and what pictures they were!—we could bask in the dazzling light of the equatorial sun; we breathed the odors of primeval forests, where the lofty cocoa palm waved its leafy top high over the thick undergrowth and the vast shades at whose feet the sleepy waves broke softly on the sandy beach of a desert isle; we looked out into the somber depths of starry nights. These were the feasts of thought. Over the open page of an atlas we dreamed, traversing the seas from the Tropics to the Poles, braving tempests and eternal ice, gathering incalculable treasures of poetic thought, the consolation and often the strength of our mature age, which, after many years, dissipated, scattered in light smoke by the wind of the tempests of life, terrible and implacable as those of the ocean, reduced to no more than the humble denier, the widow's mite, remain still the joy and blessing of old age, which advances upon us with giant strides.

Just as the thirst for discoveries was assuaged because there was nothing more to discover, the thirst for natural curiosities diminished and in its turn disappeared. Many grew tired of being enthusiastic, of admiring, when they thought that they had seen everything; they grew more tired yet of cataloguing. Moreover, it was necessary to make other use of the riches acquired than giving a name to each object, placing samples of minerals in glass cases or cellars, samples of plants between sheets of paper in a herbarium, stuffing animals and setting them in line in a gallery. Ideas became more serious; poetry and fancy gave way to science, which is in itself poetry and fancy. The intelligence of a man, following its natural bent, wished now to group the accumulation of facts in his possession under hypothetical laws, and he went to nature to verify the hypotheses suggested in his laboratory. Cook observed—that is to say, measured—the transit of Venus; Dumont d' Urville sought the southern magnetic pole; Sabine and Sir John Franklin went for the same purpose to the arctic regions. We gathered no more at random; we advanced toward a definite end.

Little by little, aided by the progress of chemistry and physics, the need of exactitude is making itself felt everywhere. We are applying it to oceanography. Realizing that it is indispensable to measure, we are no longer content to describe. We invent instruments, make chemical analyses, record figures, which are condensed facts, and true science, methodical and useful, is being evolved. At the head of each chapter on oceanography is found the name of a man of genius or of talent and an instrument. The currents of the sea have Franklin and the thermometer; the topography and lithology of submarine depths have Buache with his isobathic charts, Brooke and his detachable sounding lead, Delesse and his lithological charts; the chemistry of the sea has Forchhammer and his analyses; thermatics has Miller-Casella, then Negretti and Zambra with their differential thermometer; optics has Bérard with his porcelain plate, which shortly after becomes the disk of Secchi; physics, the mechanism of the waves, has Aimé with his mercury gage and the ball apparatus which he tested in the roadstead of Algiers, and the Weber brothers with their trough. All data are now reduced to graphical form constantly improved to approach nearer and nearer the truth, showing at a glance on each sheet of paper the picture of what is going on over the entire world in each order of phenomena, showing this even more clearly than it could be seen in nature, for on paper the phenomena are to some extent analyzed and dissected for easier comprehension of their components. We have leisure to examine separately and at the same time, by the superposition of charts having the same scale, the salinity, the temperature of the surface and of the depths, the meteorology, the contour of the bottom, its mineralogic constitution, the currents, waves, and all else. These charts permit us to combine, analyze, synthetize, experiment, sum up in every way, without fatigue or danger, without travel or loss of time. The scientist considers nature without leaving his laboratory, whither gathers the entire world to show itself in its slightest details and to unveil its mysteries.

I have not spoken of the author of theoretical and practical oceanography, founded on experimentation and measurement, as rigorous, considering the imperfections of the instruments employed, as in our own time. Marsigli founded it at one stroke. Born in Italy in 1658, successively engineer in the service of the Emperor Leopold I, slave in Turkey, member of the Academy of Sciences of Paris and of the Royal Society of London, covered with glory, ignominiously degraded from all his titles and honors, a veritable Bohemian of science, who studied the sea in Provence and published the first didactic treatise on oceanography in Holland, and whose funeral eulogy was pronounced by Fontenelle. Marsigli rose suddenly, having had neither master nor precursor. Nothing was lacking to his work. It was complete—too complete, for though admired and appreciated by a few rare, eminent minds, among others the illustrious Boerhaave, he did not found a school. Oceanography, invented by Marsigli in the last years of the seventeenth century, fell into oblivion. One and a half centuries later, about 1842, his studies were taken up without much success by a Frenchman, Aimé. In spite of these two men of genius, who were merely isolated workers, the merit of important discoveries, and especially of methodical work continued uninterruptedly during a hundred years, gives to the United States the right to call themselves the founders of oceanography.

Applications of sciences result in new discoveries. The periods of ambition, of geographic discoveries, scientific discoveries, observations, generalizations, commercial or political interests, are evidently not clearly defined. They intermingle as they succeed one another. The mind goes back more than once over its steps, because attention is awakened by some point which has been passed over without attaching to it sufficient importance. Phenomena are connected with one another as are the studies to which they give rise. It is necessary for the success of the fishing industry that the formation and character of the sea bottom be noted and submarine lithology be observed, because the skate lives in mud, the sole in sand, and the gurnet among the rocks; zoology seeks to learn how temperature and salinity are distributed in the water; the telegraph industry needs very precise topographic charts of the bottoms where it proposes to lay its cables. Discoveries multiply and every science develops with each generation of men.

As soon as a science is almost complete another replaces it, or perhaps two or three are founded together, for we see that natural manifestations, believed to be of a different order, are dependent in reality on the same law. Evolution is going on. Mineralogy is only a chapter of physics and chemistry; chemistry grew out of physics; physics grew out of mathematics; natural history is differentiating into groups and sciences; paleontology becomes paleozoology, a chapter of zoology, and paleobotany a section of botany; stratigraphic geology is paleoceanography and paleogeography; light is electricity; rhythmic vibration, measurable and measured, the wave—of sound, of light, of heat, of chemical action, of electricity—rules throughout the universe; barriers fall, matter follows the laws of the mind, everything advances toward scientific unity, as in the social domain everything moves toward unity of condition—that which assures to all, in the name of their common right to life, the maximum of happiness compatible with the human condition. There is slowly evolving a glorious moral and intellectual unity of truth, of science, of force, and of peace.

Though every nation aspires to this final end, each will reach it by different ways. While we hope for the day when all will possess the same intelligence because all will possess the same needs and the same ideal, this day has not yet arrived. We see this in every event, no matter what it may be, literary, artistic, or scientific; we recognize it in the way in which oceanography has developed. The Englishman carries into his researches qualities of precision and boldness aroused by the thought of the practical utilization which he knows will result from his discoveries. The North German carries a temperament fond of work, but opinionated, slow, and diffuse; the Frenchman his ready-witted character, a discoverer, original but not persevering, submissive to routine, which he never ceases to execrate. The younger nations are profiting by the experience of their elders and inherit the improvements made in older times; they are endowed from birth with wealth of incalculable value inherited from former generations. They enter into action with the ardor, the boldness, and power of youth, and consequently with its success. They take the first rank, or will do so. They traverse in a few years all the phases which others took many centuries to pass through. In oceanography they undertake voyages of discovery, make geography, pure science, generalize, find practical applications. This is what is shown in the history of the development of the studies relating to the sea in the United States and Russia.

THE RELATION OF PLANT PHYSIOLOGY TO THE OTHER SCIENCES.[1]

By Dr. JULIUS WIESNER,
Rector of the University of Vienna.

MOST WORTHY ASSEMBLAGE: In entering upon the honorable but also responsible office of rector of our university I shall first perform the duty of thanking my honorable colleagues for the trust which placed me in this position of high esteem.

Few institutions have outlived the century so vigorously as the rectorate of this university, which has become more and more strengthened by the course of time. The reason for this lies not only in the purposeful end of this office, but equally in this, that each rector placed in the balance his greatest possible sacrifice toward the fulfillment of his task of representing, for the time, this highest academical honor. So each rector has become an example for his successor for the most conscientious fulfillment of duty. So accrued to the office an authority which will make it possible to exercise a discreet power in fulfilling the assumed responsibilities, as well as in upholding the honors and rights of the office when sustained by the wisdom of the academic senate, by the willing cooperation of all colleagues, and by the trustful demeanor of the academic youth, who have always found in the rector the promoter and chosen solicitor of their true interests.

In the alternation of faculties, and in view of the alternation between members of the mathematical-natural-science and of the philosophical-historical groups of professorships (a principle observed by common consent in the philosophical faculty), the rectorship after a period of five years fell to a representative of the first-named scientific group. I am grateful from a special combination of circumstances for the honor of bearing the rectorate in a year in which Austria celebrates the fiftieth-year jubilee of His Majesty the Emperor. You have just heard from the lips of my honored predecessor what preparations have

[1] Inaugural address delivered on the 24th of October, 1898, in the festival hall of the University of Vienna. Translated from the original German, published at Vienna, 1898.

been made by the academical senate during the preceding collegiate year for a celebration worthy of this rare occasion.

But the jubilation of the anniversary has suddenly turned to deep sadness. We still stand under the dazing influence of the horrible deed by which our noble Empress was torn from us, and we sorrow deeply with our sorely tried august Monarch, to whom we all owe so much, and not least our university.

During the more than five hundred years of its existence, the University of Vienna has passed through no more brilliant epoch than the half century just closing. We are surrounded by speaking witnesses—the building in which we gather for work and for celebration, the grandest palace that was ever built for a university, and a corps of instruction which is scarcely rivaled in the whole world.

Most of the professorships and our university institute were founded during the reign of our present Emperor, including the professorship which has been intrusted to me—exactly a quarter of a century. This was the first regular professorship of plant anatomy and physiology, not only in Austria, but above all, in any university.

In following the time honored requirement of delivering a lecture in the field of one's specialty upon the occasion of entering into the new office, two themes especially present themselves—the development of plant physiology and its present status. Since both subjects have been recently and thoroughly discussed, I have decided to take for the subject of my present address one allied to and scarcely less interesting than those, namely, "The relation of plant physiology to the other sciences."

In the narrow limits of the time allotted to me I can only attempt to sketch in a few strokes the essential features in the reciprocal action between plant physiology on the one side, and on the other side other natural sciences and the social and mental sciences, and to make clear that plant physiology represents not merely a branch for a few specialists, but that it is aided in its advance by the other sciences; that in turn it contributes to advancement in various fields of science and practical life, and, finally, that it reaches out as a many-branched whole into the Universitas literarum.

In my present address I shall use the term "plant physiology" in its broadest sense, as the whole system of teaching relative to the structure, development, and life of plants.

Like all other sciences, plant physiology has developed in response to the demands of life. As physics and chemistry had their basis in the industries, so plant physiology grew by each experience gathered from agriculture, horticulture, and sylviculture. Even if the origin of plant physiology be not historically demonstrable as a result of the demands of practical life, still a portion of our terminology would bear witness to the correctness of the assumption. Expressions like grow, blossom, and graft, designations such as leaf, stem, and root, were not introduced by botanists, but originated in practical life and passed over from the popular vocabulary into our science.

The first demonstrable beginnings of plant physiology we find among the Greek philosophers, chiefly Aristotle and Theophrastus. But in these beginnings there was no developmental capacity. In our inductive developmental period it was necessary to lay a new foundation for the doctrine of plant life. The Englishman, Stephen Hales, in the beginning of the eighteenth century, was undoubtedly the founder of plant physiology in general, and especially the founder of physical plant physiology, while the commencement of chemical plant physiology is to be referred to the Hollander, Ingenhouss. Ingenhouss is closely identified with us in this regard, that for years he resided in Vienna as physician of the Empress Maria Theresa and of Emperor Joseph II. Some of his first contributions to plant physiology were worked out in Vienna—a fact little known. Later, until the middle of this century, the science was advanced by investigators of French nationality, foremost the Swiss investigator, De Saussure. At the present time, all civilized nations, the Japanese not excluded, take part in the advancement in this field. But if in our time names like De Saussure and Boussingault stand as towering monuments and the teachings of Darwin cease not to influence our physiological conceptions, there have been for many decades German plant physiologists who stood not simply as compeers of their French and English colleagues, but without exaggeration one may venture to say that German investigators have assumed the leading rôle in the solution of the most important questions.

The present developmental period in natural sciences, so rich in unprecedented results, is characterized by the inductive method of research and by the principle of the division of labor. It required thousands of years to show mankind that the experience of all knowledge takes root, and that the human mind, with its limitations, despite the genius of occasional great men, can only by the combined work of many, each deep in his narrow specialty, arrive at the solution of the great problems of science. As a consequence, we see in all fields of research the modern socialism of scientific progress vanquishing the intellectual giants of the olden time.

The objections to the principle of the division of labor in behalf of the mental stage of the individual are well known. These are gradually disappearing, and I will leave them without discussion. But for the development of science all of the weaknesses and failures resulting from this principle will be eradicated, as I shall later demonstrate by certain examples at hand.

In the realm of botany the division of labor brought about first a separation of descriptive botany from the studies directed toward general morphology and physiology, which latter, reenforced in a measure, placed themselves in rather sharp opposition to the descriptive side.

In his epoch-making Elements of Systematic Botany, Schleiden, near the middle of the century, challenged the systematists in these words: "The time has passed wherein a man who could give the names of 6,000 plants would because of that be called a botanist, but another who knew 10,000 plants would be designated a greater botanist, and the formerly so-called systematic botany has been thrust back into its proper place of simply a hand servant of the true and exact sciences." But the systematists returned the thrust. One of her foremost representatives declared to the men of the "true science:" "If one were to collect all the positive results thus far offered by plant physiologists it would scarcely suffice to fill a nutshell." Wrong judgments lay here on both sides, such as are always called forth by insufficient knowledge and limited insight into the relation of things. The principle of the division of labor led here, as usual, first to a separation of two so closely related territories, and it was only as one of the later results of the application of this principle that they were again brought into their natural relations.

The science, however, incurred no lasting injury from the fact that descriptive botany and physiology first pursued opposite ways. In each field good constructive material was accumulated. An earlier commencement of common constructive work would only have led to complications.

A really gratifying prospect is presented when one considers how gradually systematic botany was advanced by this branch of physiology in its widest sense. Linnæus and his school could still content themselves with a very elementary form of plant description, form and position of leaves, number and arrangement of flower parts—in short, any character which a plant in flower presented to the naked eye sufficed for the end of plant description as then pursued. Now, however, a hundred thousand species of plants are known. Of orchids alone there are as many species as all the species of plants described by Linnæus put together, and it is easy to see how the few superficial characters at first used for distinction of species became wholly inadequate. Besides, descriptive botany could not content itself with simply distinguishing plant species and supplying them names.

Furthermore, it became necessary to consider the systematic arrangement of the ever-increasing species. There had also to come into play that great principle of natural science investigation which one of our most distinguished colleagues has called the "economy of science." When I speak of orchids I express the sum of all those characters which are common to these 8,000 species. This expression of the sum of common characters must possess this quality, that by it I can distinguish this plant group from all others and, besides, express their relationship to other groups. The sum total of isolated characteristics must be brought into the simplest, briefest expression possible. Linnæus sought to attain this "economy" by his artificial system. This was a good key for the determination of species while the number was still small, but it was far from being a natural system of plants. In order to attain to such a system, one had to dig deep into the development and the inner structure of plants. This permeating of systematic botany with general botanical knowledge raised this study to a height where it might with propriety be called the earlier systematic botany.

The separation of plant species proceeded, therefore, no longer, as it did earlier, upon the basis of external characters, but came to be more and more promoted through the facts furnished by anatomy and embryology. That pure physiological characters, i. e., characters that find expression in the life processes of the plant, should be brought forward to distinguish species is one of the latest discoveries. A physiological character of plants would formerly have been held as unreal. Distinguishing characters were wanted which were always to be found in dead material, such as lies in our herbaria. So long as that sort of character sufficed there was nothing to be said against the proceeding. Now, however, we meet plant forms whose scientific nature is to be recognized only in their life activities. A Swedish botanist has made the observation that rust fungi exist which on morphological characters are impossible of separation, but are characterized only in this, that they will live on one or a few species of grasses, but will not develop when transferred to other grasses which are hosts for fungi of exact morphological equivalence. The well-known black rust of grain (*Puccinia graminis*) occurs upon wheat, rye, oats, barley, and several uncultivated grasses. It was formerly supposed that the grain rust could choose at will between these species of grasses. This is, however, not the case. It is known, for example, that the rust of rye can develop on barley, but not on wheat and oats, and it is evident that several physiological forms of grain rust may be distinguished upon this ground.

So in the progress of research has come about a union between two branches of botany which appeared widely separated, so widely that it was formerly supposed that the chasm between them would never be bridged over, i. e., between systematic botany and physiology in its broadest sense—indeed physiology in the narrowest sense of the doctrine of function. It is plain that all other fields of botany stand in reciprocal relation with physiology, but it required a long time for this state of things to come about.

Nothing would seem more natural than that in scientific investigation a plant form and the function of its organs would be equally considered—to consider it as a machine, whose parts are arranged for a purpose and in their combined action accomplish an intended result.

One need not wonder, therefore, that investigations undertaken at an earlier time, with the purpose of making clear the agreement between form and function of the plant organ, wholly miscarried and led to vague speculations and barren telleology. It was in the midst of our inductive research period when these natural philosophical speculations sought to establish themselves. Once again it was the return to the inductive method and to the principle of the division of labor which cleared the way to real progress. There came about a sharp sundering of morphology from the doctrine of function—so sharp that it was regarded as dangerous and punishable for one of these subjects to deal with things pertaining to the other. Under the chastisement of Schleiden no one attempted to demonstrate the functional significance of a morphological structure. Narrow minded as this method of procedure appeared, it was to the purpose. Embryology of plant organs arose out of these conditions, and physiology was gathering richly of usable constructive material for the future.

Only a small part of morphology, which we botanists call anatomy, but which is identical with the histology of the zoologists, developed along with physiology. The greater part of morphology, which corresponds to what zoologists call anatomy, pursued its way independently of physiology.

I venture to raise the question here as to why zoology and botany have not chosen the same expression for analogous branches of their science; why under the term "anatomy" botanists and zoologists designate different things. The cause of this lies again in the principle of division of labor, which at first always leads to a sharp separation, and only after advances in scientific work does it bring about union. The development of botany proceeded independently of zoology, and vice versa.

Terminology, taken at the beginning, is not of such serious importance, but subsequently it would be in accord with the "economy of science" if in related subjects similar expressions were employed to express similar concepts. That will come to be the case; and even now in botany the expression "histology" begins to be used in the same sense as in zoology.

The collaboration of working material in the form of demonstrated facts on the side of morphology, as well as in the realm of the doctrine of function, has aided in bringing the two nearer together, and the solution of the questions as to the functional significance of morphological structures is in full tide. The most successful has been the union of morphological and physiological knowledge as regards plant tissues, the study of which, as previously mentioned, was from the first often entangled with the doctrine of function. In this way has arisen in recent times the much cultivated branch of botany to which has been given the name of physiological plant anatomy.

No field of research stands so near plant physiology as does animal physiology. Where run, above all, the boundaries of these two territories, when, in the lower stages of plant and animal organisms, it is no longer possible to distinguish with certainty between plant and animal, and when investigations are ever revealing new identities between plant and animal life? To-day we know that plants respire in the same sense and for the same purpose as animals; indeed, the forms of respiration are the same in both kingdoms. Besides ordinary respiration in which free oxygen is taken up, there is, in plants as in animals, a so-called intramolecular respiration, in which fixed oxygen in highly oxidized compounds serves to carry on respiration. The newer investigation has acquainted us in no equivocal way with the power of motion—yes, even with the sensibility of plants. Slow movements which are to be detected by change of position during growth are common in plant life, but even very lively movements such as are exhibited by swarming of certain reproductive cells (swarmspores and spermatozoids) occur frequently in the lower groups of plants. And shall one not speak of sensitiveness in plants when it is shown that external influences such as light, gravity, etc., act as an irritant which the plant receives, conducts to parts more or less distant and responds to by some definite movement or in general by some definite reaction?

The principle of the division of labor has worked here as elsewhere n the natural sciences, first separating and then bringing together. Plant physiology has gone its own way, as has also animal physiology, the one not concerning itself about the other; and only enlightened minds have first discerned the inner identities of both, and felt themselves compelled in the solution of fundamental problems to reach out for data into the apparently foreign territory of the other. Thus, one of the greatest animal physiologists of the new era, Ernst von Brucke, who once occupied this same place of honor, to which investigator we are indebted for three great fundamental contributions in the field of plant physiology.

When investigation in each of the two fields had yielded a rich fund of usable data and had placed them in an orderly arrangement, the union of the two—plant physiology and animal physiology—began. When one takes up a recent work on animal physiology he discovers with satisfaction that already much consideration is given to the facts and conclusions of plant physiology. Recently certain works upon general physiology attest the natural association into which animal and plant physiology have entered.

The relations of physics and chemistry to plant physiology lie so closely before us and are so well known that I need not here go into nearer details concerning them. But that both these great fields of investigation stand in reciprocal exchange with their younger sister, plant physiology, I will illustrate by a characteristic example. One of the foremost living plant physiologists investigated the working of osmotic force in the life of a plant. He soon had to learn that, however much the physiologists had contributed to the knowledge of this question, both in elementary and advanced works, it was not sufficient for his purpose, and thereupon it was thought necessary by him to deal with a whole series of questions in osmotics from the standpoint of pure physics. As a result, an insight was attained by which the significance and explanation of numerous processes in plant life could be arrived at. Moreover, the experiments of this plant physiologist formed the foundation upon which was built the now famous Van't Hoff's theory of osmotic pressure, which, according to this theory, comes about in a way analogous to that of gas pressure. This is not the first time that plant physiologists have taken up the question with helpful results in the theory of osmosis. The genial and many sided Dutrochet, the discoverer of "exosmosis and endosmosis," was in the front rank of plant physiologists.

As with chemistry and physics, plant physiology stands also in this relation of reciprocal exchange with meteorology and climatology. How greatly plant life is affected by meteorological conditions and how the distribution of vegetation is dependent upon climate is evident everywhere, and rich is the knowledge which plant physiologists have gained by the application of the teachings of these two sciences. But in certain investigations relating to the life processes of plants these teachings did not suffice, and so, on the part of plant physiologists, many climatological and meteorological questions had to be taken in hand. For example, one physiologist, in order to learn the mechanical effect of rain, i. e., to find out the exact force of large rain drops on leaves, determined the weight of the heaviest rain drops, the velocity of fall, and the working force of falling rain. Likewise, contributions to a more exact knowledge of the importance and significance of light to plant life were made by plant physiologists.

The connection between science and life has never been so conspicuous as now at the turning of this century, and will doubtless become yet more striking in the next century. Proud overbearance on the one hand and a capacity for misunderstanding on the other have often and for a long time maintained a sharp antagonism between science and practical life, which rested with both sides on insufficiency of knowledge and narrowness of view. Really great investigators always recognize that, as Helmholtz opportunely expressed it, knowledge alone is not the end of mankind upon the earth, but that knowledge should be applied in the affairs of practical life. Only in this sense is knowledge power, as Helmholtz thoughtfully added on the same occasion.

The great botanical reformer, Schleiden, declared in the middle of the century to his fellow-botanists, who absolutely disregarded the application of botany in practical affairs: "All the industries which make use of vegetable stuffs in manufacturing, etc., in doubtful cases ask in vain of botany for information, although it is in a position to direct and advise the industries, but it has no practical knowledge to give; knows least, often, the very plants which furnish the most important stuffs, and borrows even from artisans themselves everything outside of the circle of that systematic botany which deals only in nomenclature."

This rebuke did not pass without effect. A student of Schleiden's, the honored anatomist, Hermann Schacht, taught how to identify the commoner fibers used in spinning by microscopical characters. Soon from Austria strong impulse and effective work appeared along these lines, where, by the use of methods of investigation practiced by plant anatomists, the foundation was laid for technical microscopy and the technical study of raw material in the plant kingdom, which two studies were first placed in the curriculum of the technical high schools of Austria.

Through the use of plant physiology in questions of practical life this science came to be an aid in the administration of justice. The courts request from plant physiologists as from chemists professional opinions, and more than once has the botanical institute of our university been in a position to respond to the requests of the court.

Botany, as is well known, came early to be a strong aid in the medical science, which encouraged not plant physiology but systematic botany—in fact, called it into existence. What the diggers of roots and herb dealers in the Grecian age began, Hippocrates and other Grecian physicians continued, namely, the search for plants with healing qualities, the naming and distinguishing of which appeared in the most thoroughly collaborated materia medica of Dioscorides. Until the period of the reawakening of the arts and sciences, this work formed the chief source of botanical knowledge. The repayment of this great debt of botany to medical science was made, however, not so much by the immediate debtor—systematic botany—but chiefly through plant physiology. Let the science of medicine always remember that the subject of bacteriology, now become so important, owes its origin to botanists. It was not merely that bacteria were first differentiated by botanists, it was likewise a botanist, the late Ferdinand Cohn, director of the Institute for Plant Physiology in Breslau, who first recognized bacteria as the cause of diseases. It was he, also, who originated the well-known generic names of bacilli, micrococci, and bacteria. What importance bacteriology has come to assume in the diagnosis and etiology of disease, for hygiene, and other branches of medicine is generally known.

Likewise those branches of plant culture which gave the first impulse toward the establishment of plant physiology have in turn been richly repaid for all the suggestions and usable facts which they furnished. Agriculture, forestry, and horticulture are to-day permeated by the spirit of plant physiology, and what these practical studies have gained in scientific insight is for the most part due to plant physiology. It must be said also that agricultural chemistry has contributed materially to the principles of plant culture, but the onesidedness of the perceptions of chemical analysis, which drew conclusions as to the soil nourishment for vegetation only by comparing soil analysis with plant analysis, could only yield a one-sided solution of the question at issue, particularly that of plant nutrition. Not until synthetical research as to the nutrition of plants made upon living specimens could it be determined on the side of the plant what elements taken up from the soil serve for food, what of the material taken up is used for other purposes, and what is merely neutral. Thus agricultural chemistry, under the influence of plant physiology, has become transformed into agricultural physiology, which to-day is to be counted one of the most important studies that contribute to practical life.

The fruitful cooperation of scientific learning and of agriculture and industry may be illustrated by the following instructive example: Long before Liebig's time the farmer knew that the cultivation of leguminous crops would make the soil richer in nitrogen, in that nitrogen compounds accumulate that which can be assimilated by plants. It was also known that leguminous plants produce peculiar little tubercles on their roots, which were explained in most varied and circumstantial ways. Bacteriological investigation has shown that these tubercles constitute the habitat of certain bacteria, which obtain entrance into the roots of leguminous plants, and live there in the mutually helpful relation of symbiosis. These bacteria, which live in peas, lentils, lupines, etc., possess the remarkable capacity of bringing the nitrogen of the air contained in soil into compounds which can be assimilated by plants. Thus the old riddle was solved. If beans be planted in sterilized soil they grow less vigorously than in ordinary soil, which harbors the bacteria in question. Abundance of these peculiar bacteria in the soil increases the productiveness of leguminous crops. This knowledge has resulted in a new industry. In the famous dyeworks of Meister & Lucius, in Hochst, is generated a product called "nitragin" for the cultivation of lupines, peas, and other legumes. This "nitragin" is simply artificially increased bacteria of different species kept in the resting stage, which, added to the soil in which lupines, etc., are planted, increases the available nitrogen supply.

Similarly numerous other sciences were richly repaid in practical help by plant physiology for what they had first furnished for "working capital" in the form of knowledge and stimulus. Therein, however, the account between theory and practice is not settled. That great account will, indeed, never be canceled. With the advancement of agriculture, of commerce and industry, arise continually scientific problems, and new scientific learning and discoveries ceaselessly promote practice. Ever more and more is disappearing the old opposition between science and practice, and more and more the opinion matures that human progress rests upon the harmonious cooperation of both.

The invasion into the realm of practical life by plant physiology has called forth many relationships between it and the social sciences. What it has done in explaining the exhaustion, what it has contributed to the understanding of the significance of the forest covering for climate and for the cultivation of field and garden vegetation has benefited the social sciences. But there are besides many other relations existing between these two seemingly widely separated sciences. In order further to illustrate this I will give another example, intentionally an extreme but instructive case. For almost a century men busied themselves with the question as to how long the earth's stores of coal would last in view of the enormous increase in the use of fuel. The estimates awakened grave apprehensions, though one might reassure himself by this fact that the premises upon which such dire conclusions were based lacked very much of being accurate. Next, comes from across the ocean a more disturbing and vexatious intelligence. Through the American and English papers goes the news—reflected also in the German press—that the danger of extinction of mankind would come sooner than had hitherto been feared. Under an appeal to the authority of a great physicist it was claimed that, with the increasing consumption of mineral fuel by the various industries, all supplies of mineral coal would be exhausted within five hundred years. But the last remnants of coal—so it was further claimed—it would no longer be possible to bring out of the earth, because in the meantime the oxygen of the atmosphere, as a result of the enormous increase in combustion, would have decreased to such a limit that the air would no longer be adapted for human respiration.

The computations in question seemed to be entirely accurate, but again the assumptions were uncertain, upon which these terrible results were predicted, as indeed the whole question whose solution proceeded upon complications of a similar kind, were dealt with only from the chemical standpoint, quite disregarding the character of living organisms.

Every condition of the earth which corresponds with the Kant-Laplace theory forms the starting point for computations like those above cited. All of the earth's carbon is burned up; all of the oxygen allotted to our planet is exhausted. After cooling of the earth, the green vegetation appears and generates free oxygen under the influence of sunlight. This hypothesis derives the whole of the atmospheric oxygen from the green vegetation. Since, at that time, there was no other natural source of oxygen upon the earth besides the green plants, it followed that with increasing combustion the oxygen supply would diminish. In order to check this decrease it was advised that extensive areas of fruit trees should be planted. So it was hoped that in this way a sufficient quantity of oxygen and human sustenance would be assured to help out the inhabitants of the earth. What small agencies opposed to the harmonious working of the powers of nature!

Upon how weak a foundation the foregoing hypothesis stands may be seen from the fact that a totally opposite conclusion may be drawn from applying the premises in field experiment, with the use of certain well-established facts of plant physiology. It has been shown, for example, by the French plant physiologist, Boussingault, that the volume of carbon dioxide taken up by green plants is exactly equal to the volume of oxygen given off in the presence of sunlight. So if, as supposed, all the oxygen of our atmosphere were liberated from carbon dioxide by green plants then would the quantity of carbon dioxide of the earth's atmosphere have been seven hundred times more before the appearance of green plants than at present, while the proportion of oxygen, according to this hypothesis, would have increased from 0 to 21 per cent in volume, while the enormous proportion of carbon-dioxide would have fallen to its present mass, namely 0.03 per cent in volume. If one were to go so one-sidedly into such conclusions as happened in the hypothesis above cited it would be possible, under the assumption of such an enormous decrease of atmospheric carbon dioxide, to undertake beforehand to predict the disappearance of vegetation, indeed to foresee that both organic kingdoms—the plant and the animal world—were so ordained as to maintain continually a reciprocal influence upon each other, and the capacity of adaptation of plants and animals, bordering on the wonderful, would make possible their continuance under external conditions widely different from the present.

But the discovery of Boussingault teaches another thing. Since the quantity of carbon dioxide in the atmosphere is practically constant, namely, an average over the earth of about 0.03 per cent in volume of the atmosphere, and since the succession of elements upon the earth will not be interrupted (i. e., carbon dioxide, through combustion, respiration and putrefaction, is constantly being produced, and also through green plants—whether on this side of the world or at the antipodes—is constantly being reduced to oxygen by the agency of light), this gas can scarcely increase to a greater proportion than 0.03 per cent in volume because so constantly involved in transformation, and even a much higher rate of combustion than is now prevalent would scarcely alter the great surplus of oxygen. An important feature our question has thus far been only briefly referred to—the extraordinary capacity of organisms of adapting themselves to their environment. If the proportion of carbon dioxide in the atmosphere should notably increase because of the consumption of coal, the plant world would still adapt itself to these changed conditions. This adaptation must, however, be granted to those whose hypothesis leads to such dire consequences as previously depicted; for they must concede that the earlier vegetation of the earth endured a far greater proportion of carbon dioxide than at present, and indeed made use of it. But when the capacity of plants to adapt themselves to the proportion of carbon dioxide in the atmosphere is conceded, then the increased consumption of coal need lead to no disquietude, at least in so far as there will be no diminution of oxygen in the atmosphere.

I have dealt thus at length with this illustration, because I wished through it to indicate to what false conclusions one-sided assumptions and problematic suppositions can lead. The problem in question here is much more complicated than is often supposed, even by prominent scientists, and to the objections which I have already urged against this doctrine of disaster very many more may be added, though it must be said that the matter was never taken very seriously in scientific circles.

In the impulsiveness of its youth, natural science has framed still many other one-sided suppositions when dabbling in strange territory. Thus Liebig ascribed the downfall of the world-embracing Roman Empire to the exhaustion of the soil, to the lack of phosphoric acid and potassium in the cultivated land, brought about by "robber farming," i. e., by too-continuous overcultivation of the soil. With propriety Du Bois-Reymond rejected this theory; but, on the other hand, the historian could not agree with this critic when he said: "Roman culture disappeared because it was built upon the quicksand of æsthetics and speculation." Du Bois-Reymond likewise attempted to solve a complicated phenomenon by too simple a formula.

Inadvertently we have just touched upon the relations of the natural sciences to the mental sciences, especially of history. For a long time these relations were very uncongenial, and insufficiency of knowledge and narrow conceptions upon both sides have often enough led to severe strife. The first attempts of naturalists to engage in the solution of historical problems from their point of view, and of historians—I recall here above all Buckle—to make use of natural history teachings in historical research, did not turn out well, and on that account could scarcely contribute toward an intellectual intercourse between the two "camps," as they were referred to frequently in those times of strife. It happened more frequently that these efforts suffered a severe rejection. So the saying was: "With the knife of the physiologist one may not cultivate the hard soil of history, but to that end is needed the strong plow of the historian." Or, an eminent historian relates that it had been made clear to him that history could not permit itself to be molested by Darwin and his associates.

An eminent historical investigator who once occupied this place of honor published very recently a work on genealogy. This, the author himself said, built the bridge between the historical and the natural sciences. In this work the effort is made to present systematically genealogy as learning in all its various relations to historical, social, political, judicial, and natural science questions.

The animal physiologists as well as those of botany have busied themselves not a little with the question of the determination of sex, but they have considered this question from the ontogenetic standpoint, if I may so express it; they have simply asked, "What conditions of the parents and what influences upon them lead directly to male or to female progeny? In the above-mentioned work on genealogy the question is philogenetically treated, if I may thus again express it. The author raises the question, namely, whether inheritance is not of significance in the determination of sex; whether, to express it plainly, certain fathers or mothers, because of prominent deep-rooted peculiarities, are not destined to produce either wholly or chiefly either male or female offspring.

It is no idle fancy which our historian has brought forward for the statement and proof of this question; on the contrary, with astonishment one sees by an examination into this work on genealogy how the author has gone into the finest natural science problems of inheritance, into the subtilest phenomena accompanying creation and the beginning of sex, in order by thus bringing forward in support all available knowledge to give the greater value to his work.

The genealogical method here brought into use by the author is worthy the high consideration of biologists. He studied the genealogical history of numerous families of the nobility and found as a rule that in one, male, in another, female, descendants so predominate that the tendency toward inheritance of sex within a family can scarcely be called in question.

For further biological studies the following discovery resulting from genealogical investigations ought to be of significance: That in the human family the male element is of more weight in the formation of sex than the female.

Similarly other branches of knowledge that stand as aids to history e. g., diplomacy and paleography, the same is true also of archæology, have come to hold certain relations to the natural sciences. The study of the physical characteristics of old documents, of the substance written upon and the material used in writing, was undertaken earlier by the historians themselves. Now, microscopists of various special fields, foremost among them plant physiologists, have taken up this task; they cleared away old errors like the charta bombycina (paper made of cotton which is supposed to have preceded that made of rags), the charta corticina which proved to be papyrus, and many others, and traced the cloth or rag paper, so important to civilization, back to the eighth century of our era; whereas the historians could trace it only to the fourteenth century, and show that this paper was first invented neither by the Germans nor by the Italians, but was due to the oft illustrated inventive genius of the Arabs. Thus the history of paper was placed by the skillful work of plant physiology upon a new basis whose certainty, tested by the historical researches of the foremost historical and linguistic students, has met with fullest acknowledgment.

Plant physiology also rendered active assistance in the construction of a not unimportant bit of the history of civilization. In this direction, meanwhile, there had appeared early botanical contributions. For instance, I would recall that a professor of botany in our university, my ever-remembered teacher, Franz Unger, renowned as a plant physiologist, submitted important contributions toward a knowledge of the origin of the various cultivated grains and other cultivated plants of importance to mankind during his botanical incursions into the field of the history of civilization.

In this very territory of the history of civilization the most widely differing branches of mental and natural science become associated. For example, by such associated investigation was demonstrated the distribution of the most important cultivated plants from Asia to Greece and Italy, and from here over the rest of Europe.

The origin of wheat is lost in tradition; the Greeks considered it as a gift from Ceres, the Egyptians as one from Isis. Neither from the historical nor from the linguistic point of view is there any indication as to the origin of wheat. But the physiological character of this cereal shows that its original home must have been in the Steppes.

Again, the native habitat of barley is shrouded in darkness. But on the other hand, on linguistic grounds, the native habitat of rye—which, like wheat and barley, is one of the Steppe grasses—is to be sought between the Alps and the Black Sea.

The distribution of many of the more valuable species of fruits from western Asia through Italy to us has been confirmed on historical, linguistic, and natural science grounds. The home of the peach (*persica*) lies in Asia, perhaps, as the name signifies, in Persia.[1] In the days of the Roman republic the peach was unknown, and is first mentioned in writings of the first century of the empire. The culture of the peach tree in Italy was begun and prosecuted by slaves and freedmen from western Asia, who, moreover, established the famous fruit-culture of the Romans.

Likewise the cultivation of vegetables spread from Italy over Europe, as the names of many vegetables show; for example, the name "kohl" for our commonest vegetable (cabbage) is taken from the Latin word caulis.[2]

Plant physiology, like every science, whether it be only through bringing forward explanatory figures or through systematic contribution, has stepped into association with philosophy. The attempt to gain a conception of the molecular or micellar structure of the make-up of cells, or through direct observation to disclose the ultimate life unit of the plant through known facts, belongs, as does the origin of invisible atoms and molecules, in the region of metaphysics; that is, they are within the province of philosophy.

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[1] According to Buhse the peach tree grows wild in the Persian province of Ghilan.

[2] Certain varieties of "kohl" (cabbage) (e. g., the varviol) are called in lower Austrian dialect "kauli," which corresponds more nearly to the Latin stem.

Perhaps I shall not be accused of going too far if, finally, I consider a moment the somewhat phantasmically spun threads which bind plant physiology with psychology. I have in mind that work of Fechner, the founder of psychophysics, published in the stormy year of 1848, a book written with the tenderest human sympathy. It had been formerly thought that plants were incapable of locomotion, and on that basis were distinguished from animals. This view was refuted by the same facts which destroyed the long-held opinion as to the insensibility of plants. Now, the last year has brought valuable explanations of the power of sensation in plants, and many fancies of Fechner's as to the sensibility of plants have been transformed into scientifically grounded views. The reception and conduction of stimuli and response to them, as in the nervous system of animals, have been demonstrated, although these organisms have no nerves, but, as Fechner said, function often as if they had nerves. If, now, plants possess a soul in the sense employed by modern psychology, then intimacy with the life of plants would offer the psychologists much support in testing the psychical functions from the standpoint of the unity of all organized beings, and the more exact separation of these psychic functions from other life functions.

I hasten to the close, and must leave unconsidered many important relations of plant physiology to the other sciences. I have not mentioned the studies upon the adaptation of flowers to insects, and vice versa, resulting in fruit production in the former—studies which call into existence a new borderland between zoology and plant physiology. I omitted also to mention the physiological elements in plant geography, also the great assistance which mathematics has rendered our science, and must likewise pass over much besides.

I have been able to trace only in a few characteristic examples the results which issue from a consideration of the relation of plant physiology to the other sciences. Essentially my whole treatment of the subject has been merely an example, for whatever holds true in my specialty holds true likewise in every other branch of knowledge, namely, the very intimate union of each with other, often widely separated, branches of learning—a union which, with the progress of research, assumes constantly greater power.

The relation of the individual branches of science to each other proves to be so complicated, as is clear from the examples cited, that we may well conceive how all attempts must be frustrated which, from Bacon to d'Alembert and from the encyclopedists to the present time, had for their object a classification of the sciences. One can not parcel off the sciences like a building plot. We ourselves have drawn the division lines between the individual sciences, compelled by the limitations of our human mind, which necessitates us to make a division of labor. But with our advances these boundaries disappear; the individual studies, often inimically opposed, unite into a single whole. Thus science seems to be one great totality whose parts are in reciprocal relation and mutual interaction, like the organs of a living organism. I would like to consider the unity of science under the figure of a tree of life which grows upward from the earth from which one part takes its power and nutriment and in which it finds its support. The parts of this tree—roots, stem, branches, and whatever they may all be called—appear to us externally different, but within they belong together; they stand among each other continually in helpful interaction. As the organs, so are the tissues adjusted to each other, and not one of the millions of cells in a tree is without purpose, and if each cell does not stand in fast relation to all others, how also need not each single scientific question be related to all others? This can as little destroy the unity of science as the unity of organic structure of a tree can be destroyed by the fact that each cell does not stand in mutual relation with every other cell.

Wonderingly we see this tree of science develop and broaden out; but for this provision is made, namely, that this tree shall not grow even into the heavens.

After thousands of years of seeking and groping, mankind has finally discovered how he may reach high aims of knowledge in spite of the limitations of his mind, by the often slow and heavily progressing inductive method, and the principle of the division of labor, which first leads to division, but after a rich harvest binds all together. It becomes even clearer that the synthetical mental work, flowing out of the principle of division of labor, must lead to even greater conceptions, and that the number of men must be even greater who, raising themselves above the level of specialists, will be investigators in the best sense of the word.

Held in bounds by the exact nature of its work, science strides forward, ever attaining more and more of what is seemingly unattainable to the human mind, and likewise ever more clearly recognizing the unattainable as unattainable. Indeed, more and more we come face to face with the limits of our knowledge. To the Grecian thinkers it seemed a play that allowed the living to spring out of the lifeless, plants or animals from slime or damp earth. But the inductive method has led us thus far to know that, so far as observation can go, the living can arise only from the living. Even the smallest known living beings, the bacteria, do not come into being parentless, as not long since the last notes of retreat of the defense of spontaneous generation declared. In the organism itself, all that is living proceeds only out of the living—the cell from a cell, the nucleus from a nucleus—and the smallest plastid lying on the very border of microscopic observation proceeds from its like. The possibility enlarged upon by many naturalists, that in the organism living constituents can arise spontaneously, is only a reaction of the old doctrine of spontaneous generation; for, so far as investigation shows, there can rise within the organism organized substance only out of the organized. So that growth of organisms appears to us only a multiplication of what is already at hand.

The progress of research has reduced to naught all the facts that pointed toward spontaneous generation, and so we find ourselves duly forced to turn away from spontaneous generation and to regard the living substance as given, just as the physicist regards matter, and takes no further thought as to the question of its origin. The most exact research, even in the domain of matter, has led to impassable boundaries, and the old riddles of the world and all its beings remain unsolved in spite of all progress, and we know, perhaps more clearly than the thinkers of earlier science epochs, that their solution lies beyond the power of the human mind. They remain as unsolvable to the greatest philosopher as well as to the simplest understanding. Other faculties of the mind than those busied in the sober pursuit of science may undertake to show a tangible relation between eternity and our own insignificance.

The mind of the most learned, free from the shadow of its own greatness, bows with the spirit of a child before the unknowable, before that source of all Being which the greatest German poet has thus designated:

"* * * der sich selbst erschuf
Von Ewigkeit in schaffendem Beruf,
* * * der den Glauben schafft
Vertrauen, Liebe, Thätigkeit und Kraft."

PITHECANTHROPUS ERECTUS—A FORM FROM THE ANCESTRAL STOCK OF MANKIND.[1]

By Eugène Dubois.

The fossil remains upon which I have founded this new species consist of a calvarium, or skullcap, two upper molars, and a femur. With the exception of one tooth, the second upper molar on the left side, they have already been described by me in a paper published in Batavia in 1894.[2] It now seems desirable to give some special details.

It is well known that a not inconsiderable number of anatomists and zoologists hold diametrically opposite views regarding the significance of these remains. For instance, as to the skull, a few have believed that it is human, although of much more ape-like appearance than hitherto known, while others have considered it the skull of an ape far more human in character than any previously discovered. It is remarkable that only a few have believed in a third possibility, intermediate between these two views, viz, that we have before us here a transition form between apes and men that is neither man nor ape. Recently this intermediate view has made quite significant progress, and a considerable number have accepted it. As to the anthropists and pithecists, as the upholders of the extreme views may be called, the former find their fossil Java man more ape like than they at first did, while the latter have placed their most anthropoid of apes still a few steps higher on the ladder of ascent toward man. These views now tend to coincide still more, because in the meantime it has been possible to test them by an exhibition of the objects themselves, and I have been able to give further particulars, especially as to the circumstances under which the remains were found.

For the proper interpretation of these osseous remains the circumstances under which they were found is quite as important a factor as the anatomical considerations. I will therefore first give some particulars regarding their situation when discovered.

Near the remains that are the subject of this paper I have collected in

[1] Part of a paper read before the Berlin Anthropological Society on the 14th of December, 1896. Translated from the Anatomischer Anzeiger, Vol. XII, pp. 1–22.

[2] Pithecanthropus erectus, eine menschenähnliche Übergangsform aus Java. Batavia Landesdruckerei, 1894.

Java, at Trinil, in the Ngawa district of the Madiun Residency, a great number of fossil skeletal parts of other vertebrate animals belonging to the same species as those found by me during five years of researches at many other places in the same strata, which lie exposed over some hundreds of square kilometers. To judge from the uplifting which these strata have undergone, in the course of which they have all been tilted (at Trinil about 5 degrees south), and also from other geological evidence, they are older than the Pleistocene, apparently older than the early Pliocene. They are of a fluviatile character, and lie, more than

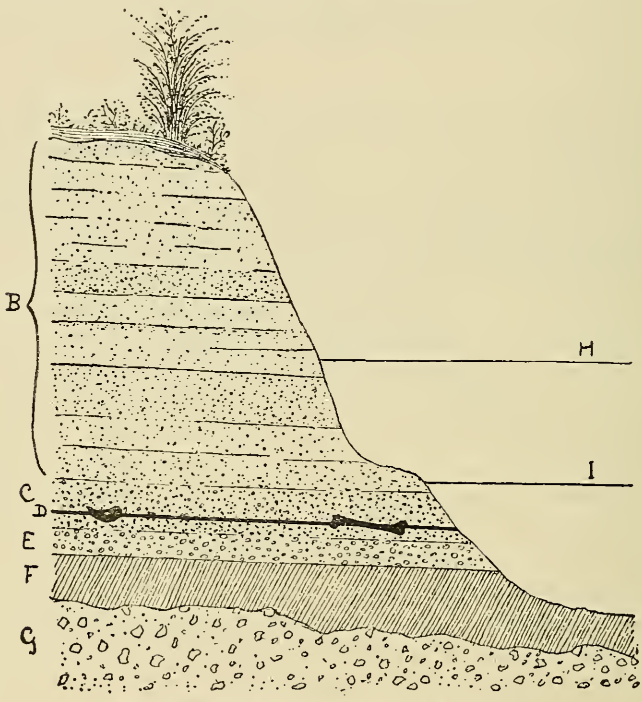

FIG. I.—Section of the ossiferous strata at Trinil

A, area of growing plants; B, soft sandstone; C, lapilli stratum; D, level at which the skeletal remains were found; E, conglomerate; F, argillaceous layer; G, marine breccia: H, wet-season level of the river; I, dry-season level of the river.

350 meters thick, unconformably, upon marine strata, which K. Martin, in Leyden, has determined as Pliocene.

According to the fauna, also, as far as I have been able to study it up to this time, it is highly probable that the strata are early Pliocene. This fauna is very similar to the fossil vertebrate fauna of western India, but appears to be younger than the Siwalik fauna of the early Miocene or later Pliocene and somewhat older than the fauna of Narbada, which has been placed in the earliest Pleistocene.

At the place where the remains were discovered at Trinil the strata, everywhere composed of volcanic tufa, lie exposed in the cliff-like declivity of the bank of a river of considerable size, the Bengawan, or Solo. They usually consist here of a sandstone of slight consistency which, in its deeper layers, at about the level of the river during the dry season, becomes coarser and coarser as more and more lapilli or volcanic stones form part of its composition. The bones are found throughout the entire thickness of the sandstone strata, being very numerous in the lower half, and most so in the stratum, about 1 meter thick, in which the lapilli are found. In the conglomerate which lies under this I found but few, and none at all in the subjacent argillaceous layer.

The four fragments of the skeleton of Pithecanthropus were found in different years, because, on account of the rise in the river during every rainy season, the excavations were necessarily suspended and could not be resumed until the next dry season. Besides, in the same working season one fragment was found later than the other, because the stone had to be removed cautiously in layers and by marked-off areas.

The four fragments were, however, found at exactly the same level in the entirely untouched lapilli stratum (fig. 1). They were therefore deposited at the same time; that is to say, they are of the same age. The teeth were distant from the skull from 1 to, at most, 3 meters; the femur was 15 meters away. The quite sharp relief of their surface does not support the theory that they have been washed out from some older layer and then embedded for a second time. They were found at the place of their original deposit. Besides they all show exactly the same state of preservation and of petrefaction as do all other bones that have been taken from this particular stratum at Trinil.[1] Their specific gravity (sp. gr. of compact tissue=2.456) is much greater than that of unpetrified bones (sp. gr. of compact tissue=1.930). The femur weighs 1 kilogram, therefore considerably more than double the weight of a recent human femur of the same size; the medullary cavity is partly filled with a stony mass. The eroded upper surface which the skullcap and not the femur shows occurred in the bed where it was found, appearing on many bones excavated near the skullcap, and is caused by infiltration of water through the cliff at that place.

Associated with these bones I also found very numerous remains of a small axis-like species of *Cervus*, frequently, also, the remains of *Stegodon*. Farther away were found *Bubalus*, apparently identical with the Siwalik species, *Leptobos*, *Boselaphus*, *Rhinoceros*, *Felis*, *Sus*, *Hyæna*, that all appear to be of new species. Of species found in other situations of the same stratum I will mention a gigantic *Manis*, more than three times the length of the existing Javanese species; a *Hippopotamus*, belonging to the same subspecies, *Hexaprotodon*, as the forms from the Siwalik and Narbada strata of western India.

Upon the evidence of these remains I determined that the four skeletal

[1] The color of the femur is also of the same chocolate brown as that of the calvarium. The latter appears to be somewhat different because it has been prepared with varnish for taking a cast.

fragments were of exactly the same age, and very probably early Pliocene. Further, these remains, in connection with the anatomical investigation of the skeletal fragments, have firmly convinced me that these fragments are all parts of one and the same skeleton. The total result of the discussion of these fragments that has been carried on by many eminent anatomists in no way contradicts this conclusion; on the contrary, it raises the presumption that it is highly improbable that they do not belong together.

A few anatomists hold that the fragments are parts of a human skeleton; according to others there is no doubt but that they belonged to individuals of the same race. Others, again, consider the femur to be quite human, while they think that the skullcap and the teeth must have belonged to the most anthropoid of all anthropoid apes. A few anatomists, however, agree with me in the opinion that a femur entirely human in character might nevertheless belong to the same individual as this ape-like skull, because a similar function would entail a similar form. Besides, this femur has certain peculiarities that I have not been able to find in a single one of some hundreds of thigh bones, so that it is not human in the usual sense of the word.

If we adopt the view that the skullcap is that of an ape, and, indeed, as must be acknowledged, that of the most man-like of all, but that the femur is that of a man, then both of these fragments must have been deposited at the same time in what was very probably an early Tertiary bed. We would then have in this case two specially important, but wholly unknown, closely related forms found together. Now, on the one hand, human bones have never been recognized below the Middle Pleistocene, much less as low as the Tertiary, and, on the other, but few remains of apes have been found, and these are much smaller, more significant, and by no means as human in character as the skullcap in question. There is therefore little probability that this view is correct. The view that these fragments were derived from different individuals of one and the same race has also very little to support it. After explorations which have been extended for five years over hundreds of square kilometers of exposed strata more than 350 meters thick and containing everywhere a numerous and homogeneous fauna, I have found, with but one possible exception, nothing which could be referred to this or any similar race.

According to all paleontological experience, the parts must have belonged to a single skeleton in case their anatomical configuration does not contradict such unity of origin. This is, however, not the case. The considerations advanced by many anatomists on this subject lead, when taken together, really to no other conclusion than that the fragments were derived from one individual. The more I myself have studied these fragments the more firmly I have been convinced of this unity of origin; and at the same time it has become ever clearer to me that they are really parts of a form intermediate between men and apes, 1

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1. *Pithecanthropus erectus*, Dubois, skull cap, from above, after photograph. One-half natural size.
2. *Anthropopithecus troglodytes*, Gmelin, adult female, skull from above, after photograph. Two-thirds natural size.

which was the ancestral stock from which man was derived. They all show, though in somewhat different degree, intermingled human and ape-like characters.

I.—THE SKULLCAP.

In the form of the skullcap similitude to that of the ape is undoubtedly predominant. Never yet has there been seen so flat and low a human skull, never yet, outside of the true apes, has so strong a projection of the orbital region been found. The skulls of Neanderthal and Spy and all microcephalic skulls are more highly vaulted, especially in the parietal region; the ratio between the central portion of the skull and the orbital part lying in front of the temporal fossa is quite the same as in the apes, differing widely from that of the lowest human skulls, even that of Neanderthal and those of microcephali. Virchow has referred especially to this. It can be seen only on the left side, the right having suffered a notable loss of substance. The part of the wall of the orbit that lies in front of the deepest portion of the temporal fossa and belongs to the zygomatic process (external angular process) of the frontal bone is, in its antero-posterior dimension, about twice as large as that of the most ape-like human skulls. Further, it would be difficult to find in a human skull so strongly developed a *torus occipitalis transversus* as that of the Javanese skull, and the lower part of the *squama temporalis* of that specimen retreats outwardly, as it does in the apes.

Those who have followed the history of the Neanderthal skull are aware that there has never existed regarding it such divergence of opinion as to its man- or ape-like qualities as has arisen concerning the Pithecanthropus. The two opposed views in that case were: Ape-like man or diseased man; the native of the Neanderthal has from the very first always been considered as an undoubted, real man. The human character of the Pithecanthropus is, however, very questionable. The skull of the gibbon almost doubled in size would not be very different from it in external appearance.

Its considerably greater size constitutes a significant difference between it and all other skulls of apes. In the length and breadth measurements of the skull the chimpanzee is exactly a mean between it and the largest gibbon. Its cranial capacity I estimated in my above-mentioned description, according to a comparison of the external lineal dimensions, as about 1,000 c. cm. Estimating now upon a more recent comparison of the internal linear dimensions with those of gibbons' skulls makes it but little more than 900 c. cm.[1] A capac ty of 900 c. cm. is, however, far above anything we know in the skull of apes. The largest skulls of anthropoid apes have, on the average, no greater capacity than about 500 c. cm., and it is very seldom that they have been found to attain the capacity of 600 c. cm.

[1] Besides the method of estimating the capacity which I detailed in my last description, and which I again applied after removing the siliceous matter from the

Disregarding this, some believe that the skull may have belonged to a true ape. If we should imagine the skull of Hylobates agilis to have somewhat more than doubled its mass, we should have a skull of a similar great ape. But if in actual fact a Hylobates had reached such a size, it is quite certain that his cranial capacity would not have increased in the same degree, for we continually find in the most diverse families that large animals have relatively smaller brains than smaller allied species. For example, the dwarf antelope (*Nanotragus pygmæus*) has in proportion to its bodily weight more than four times as much brain as the Beisa antelope.[1] The smaller lower apes very much surpass in this respect the large anthropoid apes, and the gibbons possess, in proportion to their bodily weight, at least twice as much brain as the great anthropoids.[2]

Such an imaginary gigantic Hylobates would be about as tall as a man and about as heavy as the great anthropoids. Its cranial capacity would therefore not exceed some 500 c. cm. But this is only a little more than that of Pithecanthropus. A true ape with a capacity of 900 c. cm., must, on the contrary, be a giant besides which the largest gorillas would be dwarfs. Even if the bodily size increased only in

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cavity of the skullcap so that I could compare the dimensions of the cranial cavities, two other methods were also used by me, as follows:

A. (1) The external volume of a skullcap above a plane passed symmetrically through the glabella and the external occipital protuberance was determined. (2) Its surface was found by weighing a tin-foil covering that had been spread over it. (3) Its internal capacity was approximately determined by deducting from the value found under (1) the product of the surface found under (2) with the medium thickness of the skull plus the volume of the frontal sinuses. From the result thus obtained (540 c. cm.) the capacity of the entire Pithecanthropus skull was established by (4) comparing with it skulls of Hylobates of as similar build as possible, whose skullcap capacity and total cranial capacity has been determined by direct measurement.

B. After the siliceous matter had been for the most part removed from the skullcap, this was also directly measured by filling it up to the above-mentioned plane with mustard seed and adding to this volume the estimated volume of the siliceous matter yet remaining. I found that the above-mentioned portion of the cavity of the skullcap measured about 550 c. cm. The cast of the cavity of the Neanderthal skull taken to the same plane measures 750 c. cm.

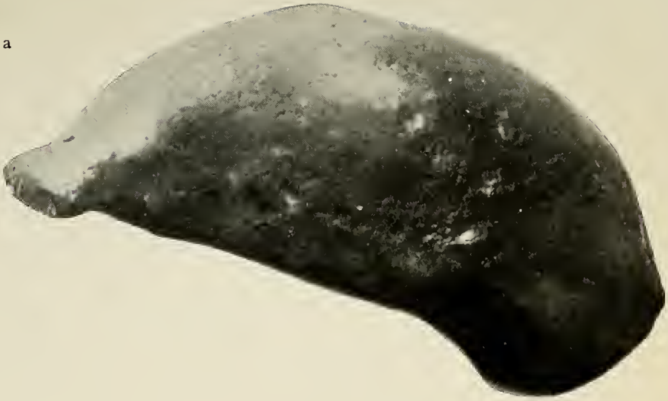
It is well known that Huxley estimated the entire capacity of the Neanderthal skull at 1,236 c. cm. The ratio of the capacity of the skullcap to that of the entire skull is, therefore, 3:5. In a skull of the Hylobates agilis, which, though only half the size, strikingly resembles that of Pithecanthropus, I find the same ratio.

According to all these methods, the total cranial capacity of the Pithecanthropus skull is found to be 900 c. cm., or somewhat more. The difference between this and my earlier estimates (compare also the Verhandl. der Berliner Gesellschaft für Anthropologie, 1895, p. 728) depends upon this, that in the first I did not allow sufficiently for the thickness of the skull (it is about 6 mm.), and secondly I could not directly compare the cavity of the skullcap.

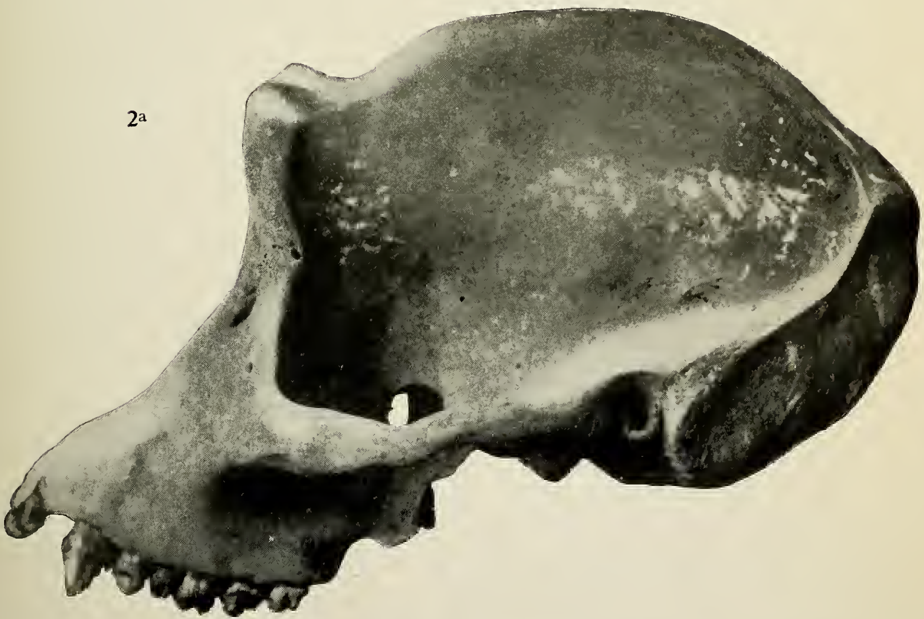
[1] According to Max Weber, Waarnemingen over het hersengewicht van zoogdieren. Bijdragen tot de Dierkunde, Amsterdam, 1888, p. 14.

[2] Compare the statements of Owen, Comparative Anatomy, Vol. III, p. 143, and M. Weber, Zool. Ergebnisse einer Reise in Niederländisch Ost-Indien, pp. 99, 100.

1a



2a



1*a*. *Pithecanthropus erectus*, Dubois, skull cap, from left side, after a photograph. One-half natural size.
2*b*. *Anthropopithecus troglodytes*, Gmelin, skull, from left side, after a photograph. Two-thirds natural size.

the same ratio as the cranial capacity, the animal would have a body almost twice as large as that of a large gorilla. But the bodily size increases in a greater ratio than that of the brain and the cranial capacity, so that it may be assumed that the size of an anthropoid ape having a cranial capacity of 900 c. cm. would be at least three times as large as that of a large gorilla; that is to say, about as large as a pretty large horse. It is not easy to imagine an ape like that leading the tree life of the nimble Hylobates.

The cerebral portion of the skull of such a gigantic ape would, in relation to the rest of the body, be much smaller than that of the gorilla. This relatively small cranial capsule would have all the provisions for the attachment of a powerful masticatory apparatus for furnishing nourishment to the gigantic body, such as is shown by the skull of a gorilla, but in a much greater degree than in this living gigantic ape. For a jaw of such mighty proportions, which would be much larger in mass than the whole of the rest of the skull, there would have to be a zygomatic arch much more extensive and more strongly vaulted than that which the gorilla possesses. Upon the skullcap there would have been formed strong bony ridges for the attachment of the temporal muscles, and these ridges would certainly have formed crests in the middle and behind. The orbital rims would have been raised in a much more striking manner than is seen in the gorillas' skull, and the impression of the bestiality of such a gigantic ape would have been much greater.

We see, however, nothing of this in this fossil skull. It is as smooth, even, and destitute of crest as the skull of an ordinary gibbon.

The skullcap, therefore, in spite of its ape-like appearance, can not have belonged to an ape, because in its excessive capacity it is dissimilar to both a gibbon's skull and that of a great gorilla.

There are, however, some features that separate this skull from that of the apes of the Old World and ally it to that of men. These concern the occiput. As already remarked above, there is a peculiar formation occasioned by the abrupt separation of the *planum nuchale* from the upper part of the *squama occipitalis*, determined by the *torus occipitalis transversus*, which is certainly a pithecoid feature; compare the inclination of the *planum nuchale* to a plane formed symmetrically through the most prominent part of the glabella and of the external occipital protuberance, and it will be seen that in this respect there is a great difference between this skull and those of all the apes of the Old World. The most diverse species of the latter show a slighter variation with each other regarding the angle between the nuchal plane and the glabello-protuberantial plane than is shown between them and the fossil skull. Among the anthropoids I find not more than three degrees of variation; in *Semnopithecus maurus* the inclination of the nuchal surface is 4° less, and in *Macacus cynomolgus* it is 10° less than the minimum among the anthropoids. In the Java skullcap, however, it surpasses the maximum of anthropoids by 18°, being, nevertheless, but 9° below the Spy skull No. 2, and about 12° below the usual angle in recent human skulls.

The apes of the New World are in this respect much nearer to man than even the anthropoids. In an *Ateles beelzebuth*, for example, I find the angle of inclination of the nuchal surface 11°, in a *Cebus niger* 7° greater than the maximum of anthropoids. Indeed many other things in their cranial formation are more similar to that of man. The platyrrhines stand, however, so far from man in other respects that they are excluded from any closer comparison. In any case there is in this

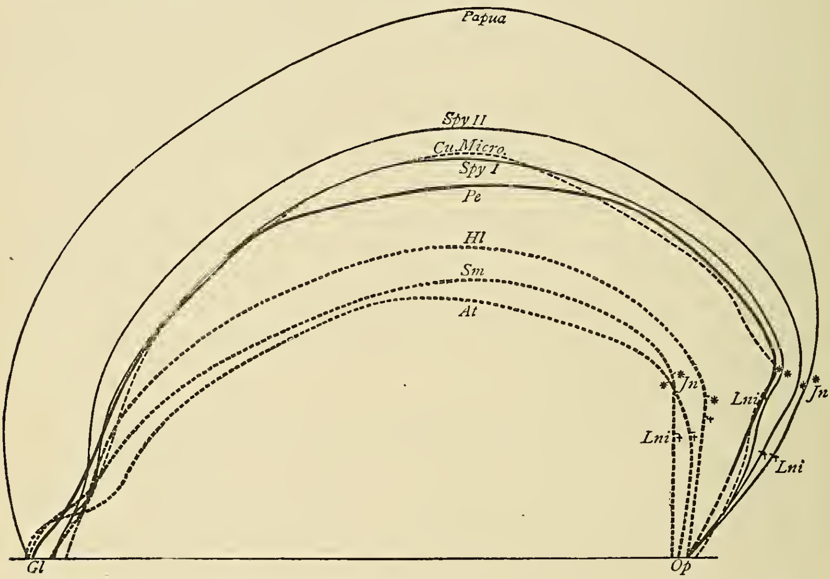


FIG. 2.—Profile curves of the skulls of Pithecanthropus erectus (Pe), a Papuaman, the Spyman (I), Cunningham's microcephalous Joe, Hylobates leuciscus (Hl), Anthropopithecus troglodytes (At), and Semnopithecus maurus (Sm). Glabella (Gl), Opisthion (Op). Linea nuchæ superior (Jn). Linea nuchæ inferior (Lni). (Figure from Transactions of Royal Dublin Society, February, 1896.)

feature not an accidental but an essential difference between the anthropoid skull of Java and those of the anthropoid apes.

In man the strong forward inclination of the nuchal portion of the occipital bone is considered to have a relation to the upright position. I can not see why it should not be interpreted in the same way in the fossil skull under consideration.

By the removal of the siliceous matter from the interior of the skullcap, which was at first partially and afterwards quite completely effected, it was shown that the *sulcus transversus* of the occipital bone, which, as place of attachment for the tentorium, marks the boundary between the cerebrum and the cerebellum, lies at about the same relative distance from the superior curved line of the bone as it does in the gibbons.[1] By laying bare the *sulcus transversus* we have obtained a more fixed point of departure for measuring the height of the skullcap as an expression of the relative extent of the cerebrum. Accordingly, we find that the skull of Pithecanthropus was almost as highly vaulted as that of the Spy and Neanderthal men, remaining, however, far below the vaulting of the skulls of recent men. The exceptionally highly vaulted skull of Hylobates agilis, inclosed, however, a cerebrum that reached nearly to the upward curve of the Neanderthal man. The remaining apes fall in regular series. Cunningham's microcephalous boy Joe has a flatter brain than the gibbon and the chimpanzee.

The breadth indices of the skulls represented here are about the same; therefore the height of each profile curve is an approximate measure for the relative sizes of the cerebrums.

If, then, the former possessor of this cranium was not an ape, and if he possibly walked erect, must he then have been a man?

I think that the ape-like form of the skullcap and its capacity, too small for a man, can not be brought to harmonize with such a conception. Even Cunningham, who has examined the skull, and is convinced that it is human, finds that its ape-like characters greatly predominate, and that there is nothing human about it except its excessive size for an ape. Virchow has also, after a personal examination of the skullcap, very clearly adjudged it, in Leyden and Berlin, as the skull of an ape. So experienced a craniologist as Hamy, in Paris, said, after examining the same, that he never would have supposed it to be human. On the contrary, the most ape-like human skulls that are anywhere known, the Neanderthal, the Spy, and the Australian skulls, were not considered by any as apes. It was only questioned concerning these skulls whether or not their resemblance to the pithecoids should lead us to give to that race a higher phylogenetic significance.

According to the conception which we have of the human skull, the Java skullcap is certainly not a human relic.

But the size also is not adapted to that of the human skull. For it is quite inadmissible to suppose that we are here dealing with a microcephalous skull, not only on account of the great improbability of such a view, but also because its form is quite different. We are certainly acquainted with normal human skulls of an equally small capacity; but

[1] As I have been able to remove only a quite small portion of the siliceous matter from the cavity of the skullcap, I, as well as others, had erroneously (as now appears, misled by its different position on the right and left sides) taken the lower edge of the sulcus transversus for its upper one. I now find that it lies considerably higher than I had at first supposed. On the other hand it appears from an examination of a large series of gibbon skulls that the average distance from the superior curved line is somewhat greater than I had previously stated. My present data are therefore more correct than those given in the Verhandlungen der Berliner Gesellschaft für Anthropologie 1895, p. 731. The similarity to the gibbon is therefore much greater.

these appear less "bestial" the smaller they get, while, on the contrary, the very "bestial" Neanderthal and Spy skulls are very large. The smaller the absolute size of a cranium is, within the same species of mammals, the more significant is its relative size as compared with the rest of the body, and the more reduced are those features of the cranium that have directly to do with the size of the body and are especially related to the skeleton of the face. It is exactly these features that constitute the bestial marks of any skull.

A skull that in comparison with that of normal man is so small and so ape-like in its form that it is declared by not a few experienced anatomists to be the skull of an ape, can not be human!

The fossil skullcap has been, with more or less strong conviction, interpreted as follows:

As that of an ape by—	As that of a man by—	As an intermediate form by—
R. Virchow.[1]	W. Turner.[6]	E. Dubois.[13]
W. Krause.[2]	D. J. Cunningham.[7]	L. Manouvrier.[14]
W. Waldeyer.[3]	A. Keith.[8]	O. C. Marsh.[15]
O. Hamann.[4]	R. Lydekker.[9]	E. Haeckel.[16]
H. Ten Kate.[5]	Rud. Martin.[10]	A. Nehring.[17]
	P. Matschie.[11]	R. Verneau.[18]
	P. Topinard.[12]	A. Pettit.[19]

[1] Verhandl. Berl. Anthrop. Ges. 1895, pp. 81, 336, 435, and Die Nation, 1895, No. 4, p. 53.
[2] Ibid., p. 78.
[3] Ibid., p. 88, and Anthrop. Congress, Kassel. 1895.
[4] Gegenwart, Januar, 1895, p. 5.
[5] Nederlandsch Koloniaal Centraalblad, 1895, p. 128.
[6] Journal of Anatomy and Physiology, 1895, vol. 29, pp. 424–445.
[7] Nature, vol. 51, 1895, pp. 428–429.
[8] Science Progress, 1895, vol. 3, pp. 348–369, and Proceed. Anat. Soc. February, 1895.
[9] Nature, vol. 51, 1895, p. 291.
[10] Globus, Bd. 67, 1895, pp. 213–217.
[11] Naturwissenschaftl. Wochenschr., Bd. 10, pp. 81, 82.
[12] L'Anthropologie, 1895, tome 6, No. 5, pp. 605–607.
[13] Jaarbock v. h. Mynwezen in Nederlandsch Indie, 1892. Pithecanthropus erectus, etc., Batavia, 1894. Leidener Zool. Congress, September 21, 1895. Roy. Dublin Society, November 20, 1895. Anthrop. Institute of Great Britain and Ireland, November 25, 1895. Berliner Gesellschaft f. Anthropol., December 14, 1895, etc.
[14] Bulletin Soc. d'Anthrop. de Paris, 1895 (6), 6, p. 12; 47 Revue Scientifique, série 4, tome 5, Mars 7, 1896, pp. 289–299.
[15] American Journal of Science, 1895, vol. 69, pp. 144–147.
[16] E. Haeckel, Systematische Phylogenie der Wirbeltiere, Berlin, 1895, p. 633.
[17] Naturwissenschaftl. Wochenschr., 1895.
[18] L'Anthropologie, 1895, tome 6, pp. 725, 726.
[19] Ibid., p. 726. Earlier (ibid., pp. 65–69) he considered it as human.

In opposition to the view of the human character of the fossil skull, the two other views taken together constitute a majority, which certainly would be considerably greater, namely, by an increase of the pithecanthropists, if all the learned people who have expressed an opinion upon this fundamental specimen had openly published their views about it. It may also appear questionable whether this majority might not be increased through later expressions of the authors above cited.

For example, Cunningham is now of the opinion that the fossil skull belonged to an individual with strongly marked simian characters.[1] He might on this account be properly placed under the first category.

In a praiseworthy manner Manouvrier,[2] in a recently published figure, has undertaken to restore the skull of Pithecanthropus according to the cast. Before this I had tried the same thing, especially for my own satisfaction, in order that I might be clear as to the result of such an unprejudiced restoration. After the emptying of the skullcap I have now tried it again. The fact that I have arrived at different results

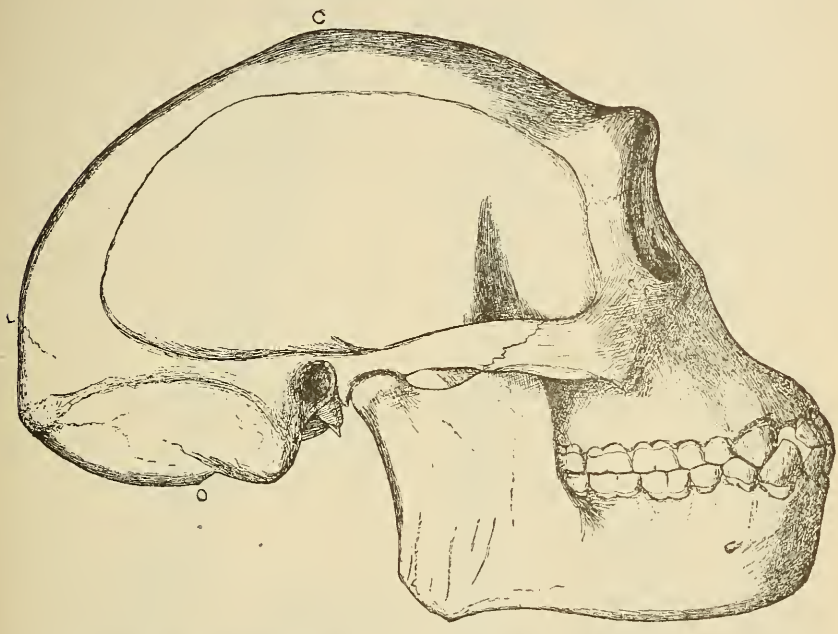


FIG. 3.—Attempt at a restoration of the skull of the Pithecanthropus erectus half the natural size C, coronal suture; O, foramen magnum.

The following corrections should be made in this figure: The point O (posterior border of the foramen magnum) is about 3 mm. (in the half-sized figure; in nature, therefore, 6 mm.) too high. Also the posterior part of the Linea temporalis is about 3 mm. (in natural size about 6 mm.) too low.

than those of the worthy Parisian anthropologist in some not unimportant points arises chiefly from this, that I had resort to the emptied fossil skullcap itself for the restoration, which caused me to consider the temporal and occipital regions somewhat differently from what Mannouvrier did. It is this that induces me to now publish my restoration also.

Especially of the temporal region I will again say that it has the very greatest similarity to that of the adult gibbon, and indeed the entire skullcap, with the exception of the strongly inclined planum nuchale of

[1] Nature, vol. 53, 1895, pp. 116 and 296.

[2] Revue Scientifique, série 4, tome 5, Mars 7, 1896, p. 294.

the occiput, has the greatest likeness—only being double the size—to the highly vaulted skull of a gibbon. It is not strange, therefore, that I have made the facial portion of the skull not very different from that of the gibbon.

II.—TEETH.

The teeth, a left second upper molar and a third right upper molar, belong, if we may judge from the circumstances of their discovery, to each other and to the skullcap. They are also modeled in a very similar manner and are in the same state of preservation and of petrifaction. The unequal wear of their crowns and the considerable difference in their size are appearances that can often be seen both in the skulls of men and of apes. Both have very strongly diverging roots, such as others as well as myself acknowledge never to have seen in human molars. Only exceptionally are there found in man upper molars with a crown of such great size. I measured on a skull from New South Wales, in Virchow's laboratory, the transverse and sagittal diameters of a left second upper molar, finding it 15.5 by 12.5 mm., and those of a third left upper molar, finding it 15 to 10.5 mm. The same dimensions of the fossil molars from Java are 14 by 12 mm. for the second upper molar, and 15.3 by 11.3 mm. for the third upper molar. A second upper molar from the cave of Spy I found to be of exactly the same dimensions as the molar from Java.

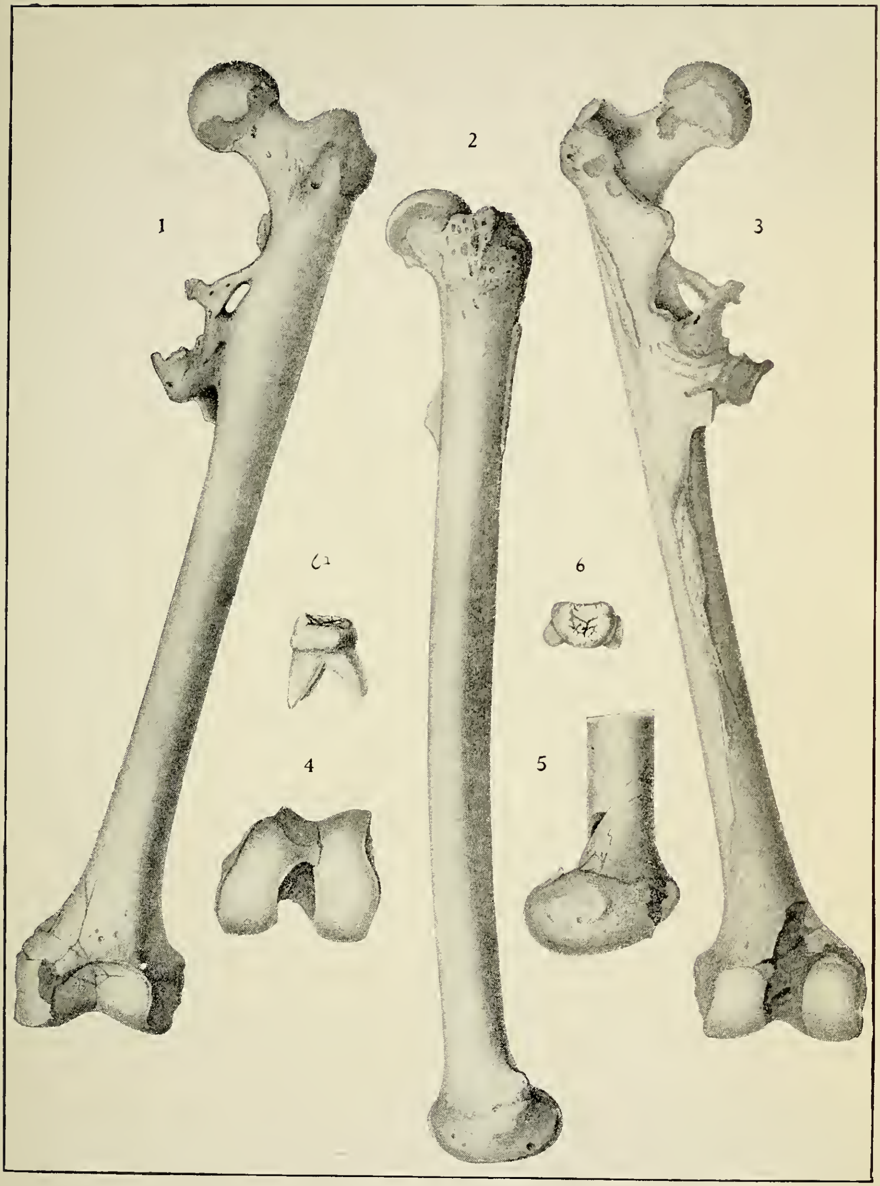
In the form of the crown the Javanese molars show a marked ape-like type; that is to say, in the relative development of their cusps. As in anthropoid apes, the posterior buccal cusp is in both teeth the smallest, so that the cusps of both are smallest on the outer side. In man the reverse is the case. Only in the third molar is an exception to this rule rarely found.

An exhaustive comparison has, however, convinced me that the teeth are in no closer relation to those of any of the living anthropoids.

In spite of all their simian characters, both, especially in the third molar, show a strong retrogression of the crown, such as is more frequently found in man than in the anthropoid apes. According to this the general arrangement of the dental arch must have been widely different from that which obtains with the great anthropoid apes. Comparing the size of the teeth with that of the skull, the proportion is found to be the same as that in the gibbon, but somewhat less than that which prevails with the anthropoid apes. They therefore agree very well with the smooth, crestless skullcap.

III.—FEMUR.

The femur was quite generally declared to be human by authors who had closely examined either the actual specimen or drawings of it. It has, as before mentioned, a very deceptive resemblance to the human femur. It differs from the latter, however, and that difference is as



PITHECANTHROPUS ERECTUS.

Left femur: 1, From before; 2, from side; 3, from behind; 4, from below; 5, lower end from median side. 6, Right 3d upper molar, from below; 6a, from behind.

great as that between bones of the same name in different but somewhat related species of mammals having a similar locomotion, as, for instance, *Colobus* and *Semnopithecus*, *Cervus* and *Antilope*. The most important difference concerns the form of the diaphyses in the popliteal region. It is much rounder than in man. The *planum popliteum* is therefore less extensive and more convex, so that exactly in its middle a kind of swelling extends as far as the neighborhood of the condyles. In the human femur the most projecting portion of the popliteal region is in the neighborhood of the lateral lip of the linea aspera. In the fossil femur, on the contrary, that lip is situated more on the lateral surface of the shaft.

After examining hundreds of human femora, Manouvrier could find only two that had a somewhat similar shape. It is therefore a very rare form in man. With the gibbon a similar form normally occurs, the median convexity in this species being, however, somewhat higher. This may be explained by the peculiar insertion of the femoral head of the biceps femoris that occurs in this species, it being attached in the middle line below the adductor magnus in close connection with the vastus internus. An extension of these conditions might, as Dr. Hepburn has pointed out to me, produce the median convexity of the entire popliteal region which we find in the fossil femur. In man the popliteal space becomes flattened by reason of the wide separation of the medial and lateral muscles in this region. In those isolated cases of a similar formation, found in an examination of hundreds of femora, there may have been a simian form of muscular attachment.

The exostosis of the fossil bone—considered by me as the result of a traumatic periostitis, and by Virchow as caused by a psoas abscess that had descended from along the spinal column—appears as a so-called tendinous or aponeurotic deposit of osseous tissue, such as occurs not very infrequently in man and is also to be seen, though in a less degree, on the humerus of the skeleton of an orang-outang in the Dresden Museum. This pathological formation has no significance as regards the systematic determination of the bones.

It has been generally allowed by everyone that the femur must have belonged to an animal that walked erect. The circumstances under which it was found, in the neighborhood of the skullcap, make it very highly probable that both belonged to the same individual; and now, since we have shown that the anthropoid skullcap may not have belonged to an ape, but possibly to a being that walked upright, this probability increases quite to certainty, for this reduces the deficiency in human characters which the skullcap showed when compared with the femur. The femur is not human in the usual sense, for it, as we have seen, shows features that occur only very seldom in human femora. Besides, the similarity of form may, as before stated, be sufficiently explained by a similarity of function, so that an entirely human form of femur need not necessarily have belonged to a man, but be found likewise in some other genus. Only an examination of the entire skeleton could give a complete solution to this question.

According to the relative proportions of these parts they can not both have belonged to an ape. For an ape with such a cranial capacity would, as we have seen, have been a giant, whose femur would certainly have been much larger than twice the size of that of a siamang. But a man with a cranial capacity of 900 c.cm. would have a shorter femur; for all men, except microcephali, that have so low a capacity as this have a much smaller stature than that of 165 to 170 cm., which is the height of the individual, as calculated from the length of this femur according to human proportions. This is again an evidence that the individual in question was, in the anatomical sense, neither an ape nor a man.

With the length and breadth measurements of the skull, however, the length of the femur agrees very well, both from a human and anthropoid point of view. A man with a skullcap of these dimensions could well have had a femur of that size, and if we conceive the proportions of a siamang to be doubled, the length and breadth of the skull and the length and breadth of the femur will exactly correspond with that of Pithecanthropus.

Nothing contradicts the view that the possessor of this cranium had a body to which this femur belonged. The skull requires exactly such a femur and no other.

As, therefore, from different points of view, probability speaks most strongly in favor of the common origin of these fragments, it is carrying skepticism too far to longer doubt that both of them, and the teeth as well, belonged to one skeleton.

I believe that it now hardly admits of a doubt that this upright-walking ape-man, as I have called him, and as he is really shown to be after the most searching examination, represents a so-called transition form between men and apes, such as paleontology has often taught us to recognize between other families of mammals; and I do not hesitate now, any more than I formerly did, to regard this Pithecanthropus erectus as the immediate progenitor of the human race. This is my conviction after the most careful testing of the matter, and has only become stronger after having submitted the specimens to many anatomists.

The exact position to be assigned to the ape-man in a system is more or less a matter of taste. According to the anatomical characters ordinarily used to separate the groups of mammals, we must at any rate exclude it from the genus Homo. Unless we considerably change and extend the characters that have hitherto been considered good for the family of the Hominidæ, it can not even be admitted there. Quite the same may be said of the Simiidæ and its species.

The relation of man and of Pithecanthropus to extinct and living apes are here shown in the form of a family tree (fig. 4).

This tree is partly an expansion of that of the primates as given by Haeckel.[1] To Dryopithecus I have, according to Gandry's recent view,[2] given a place between the Cercopithecidæ and the Simiidæ. As I have already stated in my first description, I regard as the progenitor of all anthropoid apes Protohylobates, a highly generalized hypothetical form, which, as well as its nearest living relatives, Hylobates, retained, along with many human peculiarities, yet many characters from its monkey-like ancestors that came lower in the scale. As immediate

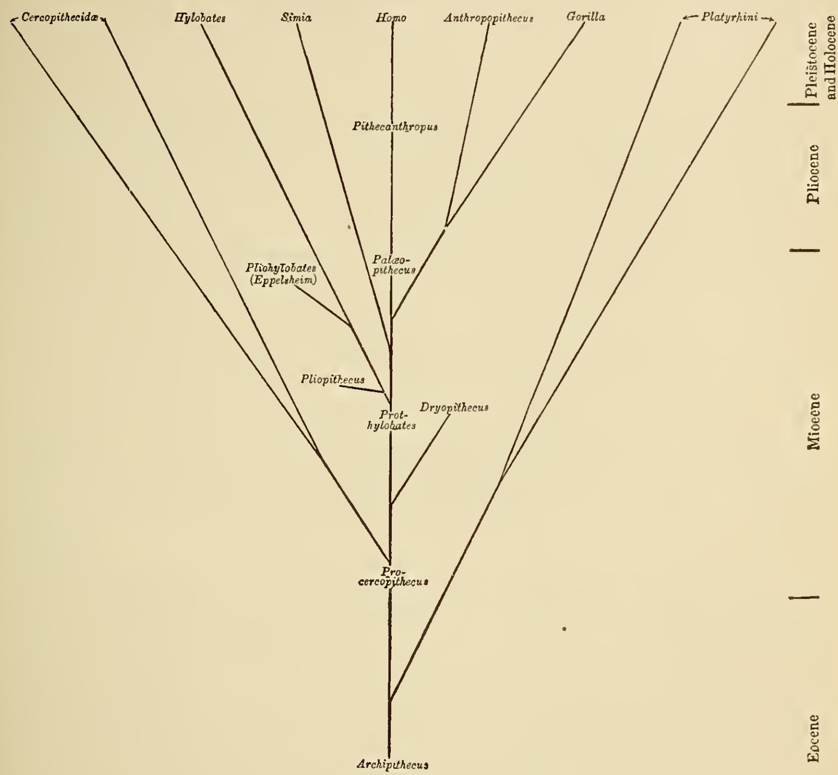


FIG. 4.—Family tree of man and apes.

ancestor of Pithecanthropus I have placed Palæopithecus of the Siwalik strata. In this also, as I have convinced myself after a careful examination of the type specimen in the museum at Calcutta, are the characters of Hylobates mingled with those of man. We first find in Pithecanthropus erectus a form in which the human characters preponderate.

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[1] E. Haeckel, Systematische Phylogenie der Wirbelthiere, Berlin, 1895, p. 601.

[2] A. Gandry, Comptes rendus de l'Académie des Sciences, T. 110, Paris, 1890, pp. 373–376.

ON OUR PRESENT KNOWLEDGE OF THE ORIGIN OF MAN.[1]

By ERNST HAECKEL.

At the close of the nineteenth century we look with just pride on the mighty and incomparable advances which human science and culture have made during its course—the natural sciences excelling all others. These facts are characteristically expressed by the statement we often hear that this is the "great" century, or the "age of natural science." Every single science that concerns itself with the knowledge and history of nature claims for itself that it can show the greatest advances and excels all others, and it can also show good ground for such an opinion. But a nonpartisan and unprejudiced philosopher who should survey the entire field would award the first prize of victory to our zoology above all others; for it was in her bosom that was born evolution, or the theory of descent, that powerful branch of the theory of development for which John Lamarck, in 1809, laid the foundation, and which fifty years later Charles Darwin brought to general attention.

It is not my task to lay before you now the fundamental significance and the priceless worth of the theory of descent. Indeed, the entire science of biology is to-day interpenetrated with it. No great and general question in zoology and botany, in anatomy and physiology, can be discussed and solved without the question of origins, "the genesis of the generated," presenting itself before everything else. This question was, however, quite unknown when Charles Darwin, the great reformer of biology, began his academic studies in Cambridge, and, indeed, as a student of divinity. This occurred in that memorable year, 1828, in which Carl Ernst von Baer published in Germany his classical "History of the development of animals," the first successful attempt to explain by "observation and reflection" the genesis of the animal body, and to investigate the "history of the growing individual in every relation," from the simplest germ throughout the completed cycle. Darwin knew nothing of these mighty advances, and he could have had no presentiment that this history of germs, embryology, or ontogeny,

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was, fifty years later, to be the most important basis of the work upon which he was to spend his life, the most secure support of that doctrine of descent which was founded by Lamarck in the very year of Darwin's birth, and which was at that time received with warm approbation by his grandfather, Erasmus Darwin.

Of all the naturalists of the nineteenth century Charles Darwin has certainly had the greatest success and the most powerful influence. We often, indeed, call the last forty years the "Darwinian age." And if we investigate more closely the causes of this unexampled success we will see, as I have repeatedly said, that they depend upon three important services rendered: (1) The total reform of the theory of descent or doctrine of Lamarck; (2) the founding of the new theory of natural selection, the special Darwinian theory; and (3) the development of the science of the evolution of man, that most important deduction from the theory of descent, which far exceeds in significance all other problems of the doctrine of evolution.

I shall to-day, before this zoological congress, speak only of the last-named service of Darwin, and do this for the especial purpose of showing critically the certainty to which we have attained in our present knowledge of the origin of man and of the various branches of his genealogical tree. That this is one of the most important of all scientific questions is to-day no longer disputed. For all other problems which the human mind can investigate and understand are conditioned chiefly by the psychological theory of perception, and this again depends upon the animal nature of man, upon his origin, his development, and his mental powers. With good reason, then, did the greatest zoologist of our century, Thomas Huxley, characterize this problem as the "question of questions for mankind," as the "problem which underlies all others and is more deeply interesting than any other." This was done in 1863 in the second of those three masterly essays which for the first time thoroughly examined the "Evidence as to man's place in nature" in the light of the Darwinian theory; the first, treating of the anthropoid apes, the second of the relations of man to the next lower animals, the third of some fossil human remains. Darwin himself, in 1859, in his principal work, On the Origin of Species, had purposely avoided referring to these consequences of his doctrine except in a brief, significant, passing allusion that, by its means, light would be thrown on the origin of man and his history. Later (1871) in his famous work on The Descent of Man, and Selection in Relation to Sex, Darwin brought forward in a most able manner, both the morphological and the historical as well as the physiological and psychological side of this problem.

I had myself, in 1886, in my Generelle Morphologie, estimated the importance of the "history of the development of organisms as bearing upon anthropology," and especially remarked that the fundamental biogenetic law held good for man also; with him, as with all other organisms, there is the most intimate causal connection between ontogeny and phylogeny founded upon progressive inheritance, between the history of the development of the germ of the individual and the history of the development of his ancestral stock. In the latter, I, at that time, distinguished ten different principal degrees within the vertebrate stock. I dwelt especially, however, upon the logical connection between the evolution of man and the theory of modification by descent; if the latter is true it gives absolute validity to the former. "The proposition that man has developed from the lower vertebrates and, indeed, immediately from the true apes is a special deduction which must necessarily result from the general induction made by the law of the theory of descent." I showed the further development and results of this conception in the various editions of my Naturliche Schöpfungs-Geschichte (first edition, 1868; ninth edition, 1898), and my Anthropogenie (first edition, 1874; fourth edition, 1891), its firm foundation was shown in the third part of my Systematische Phylogenie (1895).

It is well known that in the course of the forty years which have passed since the first publication of Darwin's theory an extensive polemical literature has appeared, relating to both its general significance and to the evolution of man, its most important result. That the latter is indissolubly connected with the former is now generally recognized, and it is exactly this intimate connection that explains the stubborn resistance that has been shown to the entire theory of evolution by all mystical and orthodox schools, by all men who have not been able to free themselves from the traditional anthropocentric superstition. In the sharp fight that has ensued on this subject the most varied weapons have been used. We can refer here only to certain exceptions based upon empirical biological grounds; we must disregard all those numerous assaults based upon metaphysical and mystical speculations made by those ignorant of the empirical but well established facts of biology. The most important part of our task will. therefore, be the critical examination of the three evidential sciences which we place at the base of all phylogenetic researches: paleontology, comparative anatomy, and ontogeny. We must cast a glance upon the advances made during the last ten years in these three auxiliaries of the science of the evolution of man and thus ascertain the degree of certainty to which a knowledge of his origin has attained by reason of these advances.

First, we have to examine the position which modern zoology, supported by comparative anatomy, gives to man in the natural system of the animal kingdom. For the aim of the natural system itself is to establish the hypothetical family tree and all the single groups, greater or smaller, which we distinguish as classes, legions, orders, families, genera, and species in the same stock are only different twigs and branches of this tree. Now, the systematic place which should be assigned to man in consideration of all the details of his bodily structure remained for a long time doubtful. When the great Lamarck, at the beginning of this century, grouped together as vertebrates the four higher of the six classes of animals, he immediately assigned to man a position at their head. Linnæus himself had already, in 1735, in his fundamental "Systema Naturæ," placed man at the head of the mammals, grouping him with the apes and the lemurs in the "Anthropomorpha," or man-like creatures; later he called these dominant animals, or "Primates," the "lords of creation."

Man possesses in his bodily structure all the marks by which mammals are separated from other vertebrates, and there has, therefore, never been any controversy about his belonging to this class. On the contrary, there are, even to this day, differences of opinion as to the place to which man should be assigned in one of the orders of mammals. Cuvier, when he made a new scientific classification of animals (1817), followed the precedent of Blumenbach and created for man the special order *Bimana*, or two-handed animals, in opposition to the apes and lemurs, who were known as the *Quadrumana*, or four-handed animals. This arrangement was retained for half a century in most text-books. It first became untenable when Huxley showed, in 1863, that it was based upon an anatomical error, and that the apes were in truth as much two-handed as man. Thereupon the order of *Primates* in the Linnæan sense was again restored.

Most authors in the last thirty years have separated the Primates into three suborders: (1) the lemurs (*Prosimiæ*); (2) the apes (*Simiæ*), and (3) men (*Anthropi*). Again, other zoologists assign to man only the rank of another family in the order of apes. The polymorphic group of true apes (*Simiæ* or *Pitheca*) falls into two natural divisions that are geographically quite distinct and have developed entirely independent of each other in the western and the eastern hemispheres. The American or western apes (*Hesperopitheca*) are distinguished by a short, bony, auditory passage and a broad nasal septum. They are therefore called the flat-nosed apes (*Platyrrhinæ*). On the contrary, the apes that inhabit Asia and Africa (in early times Europe also) have, like man, a long auditory passage and a narrow nasal septum. They are therefore called Old-World apes (*Eopitheca*), or also narrow-nosed apes (*Catarrhinæ*). As man has in the rest of his bodily structure the morphological characters of the Old-World apes and is, like them, thus distinguished from the apes of the New World, certain zoologists have assigned to him a situation within the former group. Undoubtedly this suborder of the catarrhines is an entirely natural division, whose numerous living and extinct species are clearly united by many important characters of bodily structure, but it embraces, nevertheless, a long series of very different structural stages. The lowest dog-apes (*Cynopitheca*), especially the baboons (*Papiomorpha*), appear like a repulsive caricature of the noble human form. They remain at a very low stage of development and are allied to the older platyrrhines and prosimians. On the other hand, the tailless apes (*Anthropomorpha*) rise to a height of organization that makes clear as day the immediate transition to the human form. For that reason one of the most profound students of the anatomy of primates, Robert Hartmann, went so far as to separate the entire order of primates into three families: (1) *Primarii* (man and the anthropoid apes); (2) *Simiæ*, or apes proper (catarrhines and platyrrhines); (3) *Prosimiæ* (lemurs). This arrangement seems justified by the interesting statement made by Selenka (1890) that the quite peculiar formation of the placenta of man is found in the anthropoids, but not in the other apes.

Decisive for the question as to which of these various classifications we should prefer was the proposition advanced by Huxley, in 1863, after a careful and critical examination of all the anatomical relations within the order of primates, and which I have called in his honor "Huxley's law," or Huxley's pithecometric proposition: "Whatever system of organs be studied, the comparison of their modifications in the ape series leads us to one and the same result—that the structural differences which separate man from the gorilla and the chimpanzee are not so great as those which separate the gorilla from the lower apes." Thereupon it becomes necessary for every unprejudiced taxonomist to give man a systematic place within the order of the apes. By the most conscientious testing of each difference, and by the most severe logical inference, we can, however, go a step further and instead of using the wider term apes (*Simiæ*), use the more restricted one of Old-World apes (*Catarrhinæ*). The standard pithecometric proposition would then be worded in this more exact way: "The comparative anatomy of all organs within the catarrhine group leads us to one and the same result—the morphological differences between man and the anthropomorphous Old-World apes are not so great as those which separate these anthropoids from the papiomorphous baboons, the lowest of the catarrhines."

We can now immediately utilize this incontestable pithecometric proposition, both for firmly establishing the basis of the systematic classification of the primates and for the genealogy of man. For the natural system is, within the order of the primates, an expression of genealogical relationship, just as it is in every other group of the animal and vegetable kingdoms. Hence result the following important inferences as to the genealogical tree of man: (1) The primates form a natural monophyletic group; all "dominant animals," lemurs, apes, and man himself sprang from a common original stem form, a hypothetical *Archiprimas*. (2) Of the two orders of the legion of the primates the lemurs are the lowest and oldest; from them, later, the true apes (*Simiæ*) first developed. (3) Among these latter the Old-World apes form a natural monophyletic group; their common hypothetical stem form (*Archipithecus*) is, directly or indirectly, derived from a branch of the lemurs, no matter what relation they may be assumed to have to the New-World apes. (4) Man is descended from a series of extinct Old-World apes; the more recent ancestors of this series belonged to the group of tailless anthropoid apes with five sacral vertebræ (*Anthropoides*), the older ancestors to the group of the tailed baboons with three or four sacral vertebræ (*Cynopitheca*). These four propositions are, according to our conviction, unalterably settled, no matter what further anatomical or palæontological discoveries may later do to clear up the particulars of the many steps of the phyletic evolution of man.

Comparative anatomy, which, with critical penetration, examines analytically on the one hand the structural differences of separate species of animals, and on the other systematically groups them in natural order according to their common characters, has completely demonstrated the validity of our pithecometric proposition and its significant inferences. Not less important than these morphological considerations are the physiological ones that are taught us by that instructive but hitherto, alas! too much neglected science, comparative physiology. For an unprejudiced comparison of all the activities of life teaches us that in this department also there is nowhere any radical distinction between man and apes. Our entire nutrition, secretion and circulation, breathing and digestion, are performed by the same physical and chemical processes as with the anthropoid apes. It is the same with the isolated processes of sexual activities and propagation. It is the same also for the animal functions of movement and sensation. Our mental ability results from the same physical and chemical laws as does that of the apes. The mechanics of our bony frame and the movements our muscles impart to this arrangement of levers are in no way different in man and the anthropoid apes. It was formerly thought that walking erect was a special attribute of man. We now know that this can sometimes be done by the gorilla and the chimpanzee, and especially by the gibbon.

It is quite the same with human speech. The various sounds by which apes express their sensations and their wishes, their affection, and aversion must by comparative physiology be considered as speech, just as much as are the similarly imperfect sounds that children make when learning to talk, and as the manifold tones by means of which social mammals and birds impart to each other their ideas. The modulated song of the singing bird belongs to speech just as much as the similar song of man. Besides, there exists a musical anthropoid. The singing gibbon or siamang (*Hylobates syndactylus*) begins with the fundamental tone E and goes upward through the entire chromatic scale, a full octave, in pure and sonorous half tones. The old doctrine that only man is endowed with speech and reason is still to-day held by some authoritative philologists, as, for example, Max Müller at Oxford. It is high time that this erroneous impression, resting on a lack of zoological information, should be abandoned.

Our pithecometric proposition met with the greatest difficulties and the most violent opposition in an isolated department of neuro-physiology, namely, that of psychology. The wonderful "soul of man" was thought to be a peculiar "being," and it to-day seems to many impossible that it should have been historically developed from the "soul of the ape." But in the first place the wonderful discoveries of comparative anatomy during the last ten years inform us for the first time that the minute as well as the gross structure of the brain of man is the same as that of the anthropoid apes, the unimportant difference in shape and size of single parts that exists between the two being less than the corresponding difference between the anthropoid and the lowest apes of the Old World, especially such as the baboons. Secondly, comparative ontogeny teaches us that the very highly complex brain of man has developed out of the same rudimentary form as that of all other vertebrate animals—out of five cerebral vesicles of the embryo that lie one behind the other. The special way and method by which the peculiar form of the primate brain is developed out of this extremely simple rudiment is found to be exactly the same in man as in the anthropoid apes. Thirdly, comparative physiology shows us by observation and experiment that the total functions of the brain, even consciousness and the so-called higher mental faculties, together with reflex acts, are in man preceded by the same physical and chemical phenomena as in all other mammals. Fourthly and lastly, we learn through comparative pathology that all so-called "mental diseases" in man are determined by material changes in the material of the brain, just as they are in the nearest related mammals.

An unprejudiced critical comparison confirms here also Huxley's law: the psychological differences between man and the anthropoid apes are less than the corresponding differences between the anthropoid and the lowest apes. And this physiological fact corresponds exactly with the results of an anatomical examination of the differences found in the structure of the cortex of the brain, the most important "organ of the soul." The deep significance of this information will be clearer to us when we consider the extraordinary differences in mental capacity that exist within the human species itself. There we see, high above, a Goethe and a Shakespeare, a Darwin and a Lamarck, a Spinoza and an Aristotle, and then, far below, a Veddah and an Akkah, a Bushman and a Patagonian. The enormous difference in mental capacity between these highest and lowest representatives of the human race is much greater than between the latter and the anthropoid apes.

Since, in spite of this, we find that the soul of man is to-day regarded in the widest circles as an especial "being" and as the most important witness against the decried doctrine of the descent of man from apes, we explain it on the one hand by the wretched condition of the so-called "psychology," on the other by the widespread superstition concerning the immortality of the soul. The science which to-day in most text-books and from most academic chairs is taught as "psychology" is not a true empirical science of the mind, not the physiology of the mental organs, but rather a fantastic metaphysics, compounded of one-sided introspective observation of self and of uncritical comparisons, of misunderstood data and incomplete experiments, of speculative errors and religious dogmas. Most of the so-called psychologists know nothing at all of the brain and organs of special sense, that wonderful and incomparably complex apparatus which solely and alone is the organ of the mental faculties in man and in animals. Most psychologists possess today no knowledge of the significant problems of modern experimental physiology and psychiatry, or they purposely ignore them; indeed, they know nothing at all of the actual localization of the separate mental faculties or their concurrence in the normal workings of the single portions of the brain.

The surprising disclosures which the minute anatomy and ontogeny of the human brain, assisted by experimental physiology and pathology, have made during the last four years are among the most important discoveries of the nineteenth century. Indeed, these have not hitherto been widely known, which is explained on the one hand by the great difficulty of the subject which deals with the extremely complicated structure of our brain, and on the other hand by the passive stiff-necked resistance of the dominant school of psychology. The localization of the higher mental faculties upon the cortex of the brain was effected ten years ago by the suggestive researches of Goltz, Munk, Wernicke, Edinger, and others. But recently (1894) Paul Flechsig has succeeded in marking out the single parts of this region in a definite manner; he has pointed out that in the gray cortical zone of the brain mantle there are four clearly defined regions for the central sense organs, or four "sensory spheres"—the sphere for general bodily sensibility, in the parietal lobe; the sphere for smell, in the frontal lobe; that for vision, in the occipital lobe, and that for hearing, in the temporal lobe. Between these four "seats of sensation" lie the four great seats of thought or "association centers"—the real organs of intellectual life. They are the highest apparatus of the mental faculty, on which thought and consciousness depend. In front the frontal brain, or "frontal association center;" behind and above the parietal brain or "parietal association center;" behind and below the principal brain, or "great occipito-temporal association center" (the most important of all), and finally, deep underneath, in the interior, is placed the insula brain, or "island of Reil," the "insular association center." These four seats of thought, distinguished by peculiar and highly complicated nerve structure from the intermediate seats of sensation, are the real "organs of thought," the only true apparatus of our mental life. * * *

The next question now is, What has paleontology to say regarding these important results of comparative anatomy and their application to the system of the primates and to phylogeny? For it is the petrifactions that are the true "footprints of the Creator," the immediate testimonials of the historical succession of the numerous groups of forms which have peopled this earthly ball for so many millions of years. Do petrifactions of the primates give us any determinate points of support for the above-mentioned pithecometric law? Do they directly confirm the much-disputed "descent of man from apes"? According to our view, this question must be undoubtedly answered in the affirmative. Certainly the negative gaps which we here, as elsewhere, find in paleontological knowledge are very much to be regretted, and immediately in the primate stem they are, since most of these animals lived upon trees, greater than in any other groups of animals. But to offset these wide, empty spaces we have on the other hand a continually increasing number of positive facts, and these recently discovered petrifactions have a phylogenetic value that can not be overestimated. The most important and interesting of these petrifactions of the primates is the renowned *Pithecanthropus erectus*, which Eugène Dubois found in Java in 1894. As this pliocene ape-man brought out a lively discussion at the last zoological congress held three years ago at Leyden, I may be permitted to say a few words in criticism of it.

From the proceedings of the congress at Leyden (at which I was not present), I learn that the most distinguished anatomists and zoologists expressed different views as to the nature of this remarkable *Pithecanthropus*. Its remains, a skullcap, a femur, and some teeth, were so incomplete that it was not possible to arrive at a conclusive judgment regarding them. The final result of the long and spirited debate held on this subject was that among twelve distinguished authorities three declared the fossil remains to be those of a man, three that they were those of an ape. Six or more other zoologists, on the contrary, stated what I believe to be the real fact, that they are the fossil remains of a form intermediate between ape and man. In fact the ordinary rules of logic seem to me to justify this conclusion. The *Pithecanthropus erectus* of Dubois is in fact a relic of that extinct group intermediate between man and ape to which as long ago as in 1886 I gave the name of *Pithecanthropus*. He is the long-sought "missing link" in the chain of the highest primates.

The able discoverer of *Pithecanthropus erectus*, Eugène Dubois, has not only convincingly pointed out his high significance as a "missing link," but has also shown in a very acute manner the relations which this intermediate form has on the one side to the lower races of mankind, on the other hand to the various known races of anthropoid apes, as well as to the hypothetical stem form common to this entire group of *Primaria* or *Anthropomorpha*. This common stem form Dubois calls *Protohylobates* (primitive gibbon). It has essentially the same structure as we find in the gibbon of to-day (*Hylobates*) in southern Asia, and as the fossil *Pliopithecus*, whose petrified remains have been found in the Mid-Tertiary mountains of middle Europe (in the Upper Miocene of France, Switzerland, and Styria). This in turn is derived from an older, generalized ape form which lived in the older Miocene period, and which may be regarded as the common ancestor of the Old World apes, both the tailed *Cynopitheci* and the tailless *Anthropomorpha*. Among the latter we now recognize the two living species of the gibbon which stand very near to *Pliopithecus*, as well as fossil anthropoid apes that lead directly to *Pithecanthropus*. Such an intermediate stem form is *Pliopithecus sivalensis*, whose skeleton was found in the early Tertiary layers of eastern India in the Pliocene Siwalik strata.

For forming a correct judgment concerning this important *Pithecanthropus* and its immediate position between the anthropoids and man, two features are especially valuable; first, the close resemblance of the femur to that of man, and second, the relative size of the brain. Among the few anthropoid apes yet living the gibbons appear to be the lowest and oldest, standing nearest the stem-form of all the *Anthropomorpha;* they are also the most generalized and appear especially adapted to illustrate the "transformation of apes into man." The gibbons more than the other anthropoids have the habit of voluntarily assuming the upright position, whereby they walk upon the entire sole of the foot and use their long arms as balancing poles. The other modern apes (orang, chimpanzee, and gorilla) seek the upright position, and when they use it do not tread upon the entire sole but upon the outer edge of the foot; they also have in other respects more specialized characters, adapted especially to their tree climbing life. It is thus explained why it is that it is exactly the femur, in *Hylobates* and *Pithecanthropus*, that is much more human in form than that of the gorilla, the orang, and the chimpanzee.

But also the skull, that "mysterious vessel" of the organ of the soul, approaches nearest the human proportions both in *Pithecanthropus* and in the gibbon in important particulars—the rough, bony crests which the skulls of the other anthropoids show are wanting. The relative size of the brain (in proportion to that of the entire body) is in the latter only half as great as it is in the gibbon. The capacity of the skull of *Pithecanthropus* is from 900 to 1,000 c. c., therefore about two-thirds the capacity of an average human skull. On the other hand, the largest living anthropoids show a capacity half as high as this—500 c. c. So the capacity of the skull and consequently the size of the brain is in *Pithecanthropus* exactly midway between that of the anthropoid apes and the lower races of mankind; and the same is also true for the characteristic profile line of the face. In this respect compare the skulls of the lowest and most pithecoid races of man. Among these the still living pygmies, the little Veddahs of Ceylon and the Akkas of Central Africa, are of great interest. An unprejudiced comparison of all these anatomical facts shows in no ambiguous manner the character of *Pithecanthropus* as a true intermediate form between anthropoid apes and man; he is the long sought for and much discussed "missing link" in the chain of our primate ancestors, by many regarded as of the highest importance.

To this momentous interpretation, which is now accepted by nearly all naturalists, the renowned pathologist of Berlin, Robert Virchow, set up the most obstinate opposition. He went to Leyden for the special purpose of contradicting the idea that the *Pithecanthropus* is a transitional form, but met with little success. His contention that the skull and the femur of *Pithecanthropus* could not have belonged together, that the first belonged to an ape and the second to a man, was rejected at once by the expert paleontologists present, who declared unanimously that, in view of the extremely careful and conscientious account of the discovery "there could not the slightest doubt exist that the remains belonged to one and the same individual." Virchow further asserted that a pathological exostosis in the femur of *Pithecanthropus* likewise testified to its human character, for only by the most careful attention by human hands can such disorders be cured. Immediately thereupon the famous paleontologist Marsh showed a number of similar exostoses upon the leg bones of wild apes, who had had no "nursing care," and yet had recovered. Every great osteological collection contains similar specimens; experienced hunters know that fractures and inflammations of bones in foxes, hares, harts, roebucks, etc., are often healed quite well, without the intervention of man, while those animals are in a state of freedom. Finally, Virchow asserted that the deep notch between the orbital edge and the low skullcap of *Pitheeanthropus*—a sign of a very deep conformation of the temporal fossa—were decisive for the ape-like character of the skull, and that such a formation never occurs in man. A few weeks later the paleontologist Nehring (who from the beginning had supported the just conclusion of Dubois) showed that exactly the same formation was presented by a human skull from Santos, in Brazil.

Virchow had formerly the same want of success with his "pathological significance of the skulls of the lower races of man." The famous skulls of Neanderthal, of Spy, of Moulin-Quignon, of La Naulette, etc.—which taken together are the interesting isolated remains of an extinct lower race of man standing between *Pithecanthropus* and the races of the present day—these were all declared by Virchow to be pathological products; indeed, the sagacious pathologist at last made the incredible assertion that "all organic variations are pathological;" that they are only produced through disease. According to this all our noblest cultivated products, our hunting hounds and our horses, our noble grains and our fine table fruit, are, alas! diseased natural objects that have arisen by pathological changes from the wild original forms that alone a e "healthy."

In order to make this strange assertion of Virchow intelligible, it must be remembered that for more than thirty years he has regarded it as his especial duty as a scientist to oppose the Darwinian theory and the doctrine of evolution necessarily connected with it. With the greatest obstinacy he has maintained the doctrine of the constancy of species, which is now abandoned by all naturalists of good judgment; but in what now consists the essential idea of a "true species" he can no more tell than any other opponent of evolution. The most important conclusion from the latter, the "descent of man from the ape," Virchow is well known to attack with zeal and energy. "It is quite certain that man did not descend from the apes." This assertion of the Berlin pathologist has been for twenty years past repeated innumerable times in religious and other periodicals—cited as the decisive judgment of the very highest authority—not caring in the least that now almost all experts of good judgment hold the opposite conviction. According to Virchow the ape-man is a mere "figment of a dream;" the petrified remains of *Pithecanthropus* are the palpable contradiction of such an unfounded theoretical assertion.

How directly fruitful the great advances in paleontology for the last thirty years also are for our pithecoid theory can best be shown by the example of the legion of the primates itself. Cuvier, the founder of scientific paleontology, asserted up to the time of his death (1832) that there were no petrifactions of apes; the only fossil lemur whose skull he described (*Adapis*) he erroneously took for a hoofed animal.

The first petrified remains of apes were discovered in India, in 1836, in 1838 the *Mesopithecus penthelicus* was discovered near Athens, and in 1862 further remains of lemurs. But within the last twenty years so numerous remains of extinct primates have become known to us through the discoveries of Gaudry, Filhol, Schlosser, and especially by the rich finds of the American paleontologists Marsh, Cope, Leidy, Osborn, Ameghino, and others, that we have now obtained a satisfactory general insight into the rich development of this highest legion of mammals during the Tertiary period. With great admiration I have recently seen in London the instructive series of fossil primates which is displayed in the noble paleontological section of the museum of natural history in South Kensington, in which there is a gigantic fossil lemur which was nearly as large as a man, and which Forsyth Major recently discovered upon the island of Madagascar (*Megaladapis madagascariensis*).

Now, as in Cuvier's time, the most important differences between the two principal groups of true apes consists in the characters of the teeth. Man, like the Old-World apes, possesses thirty-two teeth of very characteristic structure and arrangement. The New-World apes have, on the contrary, thirty-six teeth, namely, one more premolar in each half of either jaw. Comparative odontology is authorized to state on phylogenetic grounds that this number has arisen by reduction from a higher dental formula, from forty-four teeth; for this typical form of dentition (in each half jaw, above and below, three incisors, one canine, four premolars, and three molars) is common to all those older mammals of the Eocene period which we regard as stem-forms of the principal groups of chorion animals (*Placentalia*): *Lemuravida*, *Condylarthra*, *Esthonychida*, and *Ictopsida*. These form old Tertiary stem-forms of the primates. The *ungulates*, the *rodents*, and the *carnivores* resemble each other so much in bodily structure that we may bring them all together as a single common stem-group of the placental mammals, the primitive chorion animals (*Prochoriata*). With great probability we may now connect with this the further monophyletic hypothesis that all chorion or placental animals—from the lowest Prochoriata up to man—arose from a common unknown stem-form in the Cretaceous period, and that this oldest of the chorion animals arose from a marsupial group living in the Jurassic period.

But in fact we now possess among those numerous fossil lemurs that have been found for the first time during the last twenty years all the intermediate forms desired, all the "missing links" that are required by phyletic odontology. The oldest Prosimia of the Tertiary period, the pachylemurs (or *Hyopsodines*) of the old Eocene, have yet the original forty-four teeth of the placental stem-group; in every half jaw, above and below, three incisors, one canine, four premolars, and three molars. The necrolemurs (or *Adapides*) with forty teeth followed them; they have lost an incisor on each side above and below. Next come the younger autolemurs (or *Stenopides*) with thirty-six teeth (one premolar less); they have therefore already the same dental formula as the platyrrhines or American apes. The dentition of the catarrhines has arisen from this through loss of a second premolar. These relations are so clear and go so evidently hand in hand with the formation of the entire skull and the stronger development of the typical primate form that we may say: The general elementary features of the primate genealogical tree from the oldest Eocene lemur up to man lie clearly before our eyes within the Tertiary age; there is no longer any "missing link." The phyletic unity of the primate stock from the oldest lemur up to man is now an historical fact.

It is quite different, however, when we leave the Tertiary and in the Mesozoic period attempt to discover the oldest ancestral series of the mammals. There we meet everywhere with painful gaps in our paleontological record, and the comparatively few remains of Mesozoic mammals (especially scanty in the chalk) are insufficient to enable us to form any definite conclusions as to the systematic placing of the mammalia in question. However, comparative anatomy and ontogeny compel us to the conclusion that the Cretaceous Placentalia arose from Jurassic marsupials, and these from Triassic monotremes. We may also further suppose that among the unknown Placentalia of the chalk there were found *Lemuravida* and other *Prochoriata*; that the *Amphitheriidæ* of the Jurassic were ancestors of the marsupials, and that the monotreme ancestors of the latter are to be sought among the *Pantotheria* of the Trias. But paleontology does not at this time offer us any secure foundation for these phyletic hypotheses. Only one important piece of information is given us, that the oldest mammals of the Mesozoic age, the *Pantotheria* and *Allotheria* of the Trias, were small, lowly organized, for the most part insect eating animals that represent the derivation from older vertebrates, reptiles or amphibia. There is nothing in this to contradict the idea that the entire class of mammals, from the oldest monotremes to man, is monophyletic; that all members of it can be traced back to a single common stem-form.

This positive conviction of the phyletic unity of the class of mammals, because of its common origin from a single extinct stem-group, is now shared by all expert zoologists, and I hold it to be one of the greatest advances of modern zoology. No matter what system of organs we compare in the various mammalian orders, we everywhere find this typical agreement in the essential characters of their structure, both minute and gross. Only among mammals is the skin covered with true hairs, from which fact Oken named this class the "hairy animals." Only in this class is generally found that remarkable kind of nurture, the nourishment of the newborn child with the milk of the mother. Here lies the physiological source of that highest form of maternal love which has exercised such a significant influence upon the family life of various mammals, as well as upon the culture and higher mental life of man. The poet Chamisso justly says of this:

> Only the loving mother, only she
>   Who nurtures from its birth the child she bears,
> Knows the true joy that we call happiness,
>   Created by the love she never spares.

If the Madonna seems to us the most sublime and pure prototype of this human maternal love, yet we perceive on the other hand in the "ape love," in the excessive tenderness of the ape mother, the counterpart of the same maternal instinct. The slow development of this, in the course of many millions of years, from the Trias period to the present, goes hand in hand with an important series of transformations. For the adaptation of the new-born mammal to suckling involved a series of changes not only in its own body but in that of its mother. While in the skin of the mother the mammary glands developed through the irritation and differentiation of a group of ordinary skin glands, there was formed in the mouth of the child, by the act of sucking, the soft palate and afterwards the epiglottis—two organs of the throat that occur only in mammals. In connection with this the mechanism of breathing was changed; this is shown not only in the minute structure of the lungs, but also in the formation of a complete diaphragm. Only in mammals does the muscular diaphragm form a complete partition between the throax and the abdomen. In all other vertebrates the two cavities remain openly connected. Also in the bony framework of the body, and especially in the skull, do we find results of these important transformations. Much the most important of these is the transformation of the articulation of the mandible or lower jaw, which in mammals is quite strikingly different from that of all other vertebrates. This joint, by which the lower jaw moves upon the temporal bone, is in mammals a temporal joint, while the original joint of its reptilian and amphibian ancestors was a quadrate joint. The latter is, in the mammalia, taken up into the tympanic cavity and there represented by the articulation of two of the special bones of the ear, the malleus and the incus; the malleus was formed from the original joint piece of the lower jaw, while the incus is the quadrate bone or jaw pedicel of the reptilian ancestors.

But apart from these and other anatomical peculiarities which all mammals have in common, and which elevate them above all other vertebrates, in order to recognize their difference it will only be necessary to look at a single drop of blood under a microscope. "Blood is a very peculiar juice." The small red-blood corpuscles which, heaped up by millions, occasion the red color of the blood of vertebrates were all originally elliptical disks, thicker in the middle (biconvex), as it was here that the nucleus lay. Only in the mammals have these lost their nucleus, then appearing thinner in the middle (biconcave), as small circular disks. These and other important peculiarities occur, without exception, among all mammals, and separate them from all other vertebrates. From their peculiar combination and mutual relations they can only have been acquired once in the course of descent, and only from one stem-form can they have been transmitted by inheritance to all members of the class.

The older portion of the genealogical history of the human species leads us still farther back into the domain of the lower vertebrates, into that dark, immeasurably long age of the Paleozoic era, which with its uncounted millions of years (according to recent estimations, at least a thousand) was certainly much longer than the succeeding Mesozoic age. Here we first come upon the important fact that in the earliest portion of the Paleozoic period, in the Permian age, no mammals yet existed, but instead lung-breathing reptiles, as the oldest amnion animals. They belong partly to the *Tocosauria*, the oldest and lowest group of reptiles, partly to the strange *Theromera*, which by many characters approach the mammals. These reptiles are preceded in the lower Carboniferous period by true amphibia, such as the armored *Stegocephali*. Such Carboniferous armored amphibia, like small crocodiles, are the oldest vertebrates, who by their creeping method of locomotion adapted themselves to the firm ground, and in whom the fins of swimming fishes and the paddles of swimming amphibians (*Dipneusta*) had been modified into the typical five-fingered extremity of a four-footed animal (*Tetrapoda* or *Quadrupeda*).

We only need to compare carefully the skeleton of the four legs of our salamanders and frogs with the bony framework of our own four limbs to convince ourselves that with these amphibians the same characteristic and peculiar structure had arisen as they handed down by inheritance to all the sauropsida and mammalia; there is the same shoulder girdle and pelvic girdle, the same simple hollow bones in the upper arm and upper leg, the same pair of bones in the forearm and lower leg, the same complicated union of bones in the wrist and ankle, the same typical arrangement of five fingers and five toes. This striking agreement in the assembling of the bony framework in all the higher four-footed vertebrates struck many thoughtful observers more than a hundred years ago; among others it led our greatest poet and thinker, Goethe, to those remarkable observations on the morphology of animals that we may consider the direct precursors of the modern ideas of Darwin.

We can, in fact, show, as a certain sign of the derivation of man from the oldest five-toed or pentadactylate amphibians, the fact that we possess to-day on our hand five fingers and on our foot five toes. Man and most primates (not all) show in this and in other respects that through conservative inheritance they have preserved the original plan of structure much more closely than have the majority of other mammals, especially the ungulates. Among others the one-toed horse on the one side and the two-toed ruminants on the other, are much more modified and specialized than are the primates.

The oldest amphibia of the Carboniferous period, the armored Stegocephali (and especially the remarkable *Branchiosauria* discovered by Credner), are now quite justly considered by all discriminating zoologists as the undoubted common stem group whence were derived all four-footed animals (*Tetrapoda* or *Quadrupeda*), all amphibia and amniota. But what was the origin of this important group itself? To this question also the great advances of palæontology afford a satisfactory answer which harmonizes excellently with the older solutions given by comparative anatomy and ontogeny. Already in Jena, forty-four years ago, the first master of comparative anatomy, Carl Gegenbaur, in a series of classical essays, pointed out that the most important parts in the vertebrate skeleton, particularly the skull and the bones of the limbs, reveal to us to-day, in the succession of classes of living vertebrates, a coherent scale of phyletic steps of development. Apart from the more lowly organized *Cyclostomata* it is especially the true fishes, and among them again the primitive fishes or *Selachians* (sharks and rays), which have proved most constant to the original form in the essential relations of their bodily structure. To the *Selachians* are closely allied the ganoids or enamel fishes, especially the *Crossopterygii* which take us farther back to the *Dipneusta*. Among these last the Australian fish *Ceratodus* has recently become of great interest, its anatomy and ontology having been carefully investigated by Günther and Semon. By this transition group of *Dipneusta* or amphibious fishes—that is to say, fishes with lungs, but also with fins, with pentadactylate limbs—is the morphological bridge to the early amphibians easy to find. But this anatomical chain corresponds exactly with the paleontological facts; selachians and ganoids are already found in the Silurian formations, dipneusta in the Devonian, amphibia in the Carboniferous, reptiles in the Permian, mammalia in the Trias.

These are historical facts of the first rank. They attest in the most gratifying manner the successive steps of the development of vertebrates, as they have been made out by the comparative researches of Cuvier and Meckel, of Johannes Müller and Gegenbaur, of Owen, Huxley, and Flower. The historical succession of the principal steps in the vertebrate stock is thereby definitely established, and this success is much more important for an understanding of the human family tree than if we had succeeded in placing, in a hundred fossil skeletons of lemurs and apes, the entire series of our Tertiary primate ancestors in coherent succession before our eyes.

Much more difficult and dark is the oldest history of our stock, the derivation of a vertebrate stem from an invertebrate ancestry. As none of these possessed any hard and petrifiable parts of the skeleton (resembling in this respect the lowest vertebrates, the cyclostomata and acrania) the evidence of paleontology entirely fails us here; we must rely alone upon the other two records of our family history, upon comparative anatomy and ontogeny. To be sure, their value is here so great in many respects that for every expert and discriminating zoologist they throw the clearest light upon many great features of our older phylogeny. Of the greatest value are these far-reaching inferences which modern comparative ontogeny has drawn during the last thirty years by the aid of the fundamental biogenetic law. Already the older embryology has made clear the elements of vertebrate development by the thorough work of Baer and of Bischoff, of Remak and Kölliker. Then, in 1866, came the important discoveries of Kowalevsky, which confirmed the suspicion of Goodsir and pointed to the close relationship of vertebrates and tunicates; the comparative anatomy of Amphioxus and of the ascidians has since that time been the constant starting point for all further investigations concerning our invertebrate predecessors.

Five years investigation of the structure and development of the chalk-sponges (1867–1872) had led me at that time to a reform of the theory of the germinal layers and to advance the gastræa theory. It first appeared in 1872 in my monograph on the chalk-sponges or *Calcispongidæ*. These views obtained the most earnest support and the most fruitful development by the excellent comparative researches of many other embryologists, especially those of E. Ray-Lankester and Francis Balfour, as well as those of the brothers Oscar and Richard Hertwig. I had already then concluded from these comparative researches that the first step of development in all Metazoa, or tissue-building animals, is essentially the same, and that we may from this obtain definite insight into the common origin and the older ancestral series of the same. The unicellular ovum repeats the unicellular condition of our protozoan ancestors. The blastula germ form corresponds to a *Volvox* or *Magosphæra*, a similar ancestral form; the *Gastrula* is the inherited repetition of the *Gastræa*, the common stem form of the entire series of Metazoa. All these typical ancestral forms man shares with all the other Metazoa, that is to say with all other animals except the unicellular Protozoa. Every man, without exception, begins his individual existence in the form of a spherical egg-cell, barely visible to the naked eye, as a very small dot, and the special characters of this egg-cell are exactly the same in man as in all other mammals.

The most obscure portion of the genealogical history of man is that part which lies between *Gastræa* and *Amphioxus*. Amphioxus itself, that famous lancelet, or lancet animal, whose fundamental significance had already been recognized by its first exact describer, the great Johannes Müller, is the most precious document of vertebrate phylogeny. We should not indeed consider it as a stem ancestor to vertebrates, but rather as a near relation to such, and as a unique living relic of the class of acrania. Had the amphioxus accidentally perished, like so many other links in our ancestral chain, we would hardly be in a position to obtain any satisfactory insight into the older steps that led to the formation of vertebrates. Above amphioxus stand its near relations, the *Cyclostomata* or round-mouths. These are the oldest *Craniota* or skulled animals, the first vertebrates that succeeded in obtaining a skull and brain. These *Cyclostomata* (among whom the well-known lamprey, *Petromyzon*, belongs) are, at the same time, the presilurian forerunners of fishes. Below amphioxus we find that the agreement between the ontogeny of amphioxus and the ascidians points to an unknown older group of chorda animals, the *Prochordonia*, from which have developed on the one hand the tunicates, on the other the vertebrates. We may derive these prochordonia, or primitive chorda animals, from the *Frontonia*, a twig of the *Vermalia*, or true worms. The isolated *Balanoglossus* and the old *Nemertina* are probably closely related to these. There certainly existed, in the Cambrian and Laurentian periods, between these worms and the stem group of the *Gastræades*, a long series of intermediate forms, and we suppose that the older *Rotatoria* and *Turbellaria* belonged in this series. But we can not at this time form any well-grounded hypothesis on this point, and there is indeed here a wide empty space in our genealogical history.

But contrasted with these and other obscure portions of our family history stand out clearly and significantly the conclusions which the rich results of comparative anatomy, ontogeny, and palæontology have given in the investigation of the vertebrate stock, and especially of that of its highest class of mammals. All reliable recent researches have here unanimously confirmed the proposition which Lamarck, Darwin, and Huxley declared to be the most important result of the theory of evolution—the proposition that the immediate placental ancestors of man were a series of tertiary primates, and the next nearest were the anthropoid apes, the anthropomorphous catarrhines. The careful critical comparisons which the two zoologists, Paul and Fritz Sarasin, have accomplished in their fine work. Researches in Ceylon (1893) shows that the Veddahs of to-day, the dwarfish aborigines of Ceylon, approach nearest to the anthropoid apes in the primitive relations of their bodily structure, and that among the latter the chimpanzee on the one side and the gorilla on the other stand nearest to man. The gibbon again, as a lower and less specialized form, shows the closest agreement with the common miocene ancestors of all the Anthropomorpha. This direct family relationship is much clearer and easier to settle than that of any other mammal. Far more obscure and enigmatical is, for example, that of the elephants, the sirenia, the cetacea, the edentates (armadillos and pangolins) in both hemispheres. Not only in his pentadactylate hands and feet, but also in other anatomical features does man show the characteristic inherited features of his stock more clearly than many other mammals, as, for example, ungulates, cetaceans, and bats.

The immeasurable significance which this secure knowledge of the primate origin of man possesses for the entire range of human science lies clear before the eyes of every unprejudiced and logical thinker. No one among the philosophers has more thoroughly based his authoritative influence upon a contemplation of the entire universe than has the great English thinker Herbert Spencer, one of the few learned men of the present day who unites the most profound scientific training with the deepest philosophical speculation. Spencer belongs to those older nature philosophers who already before Darwin recognized in the monistic theory of evolution the magic key which would unlock the riddle of the world. He belongs also to those evolutionists who justly lay the greatest stress upon progressive inheritance, upon the "transmission of acquired characters." Like myself, Spencer has, from the beginning, fought in the most resolute manner the germ-plasm theory of Weismann, which denies the most important factor in the theory of descent and wishes to explain the same chiefly through the omnipotence of natural selection.

In England the theory of Weismann has been received with much approval, and is also known as neo-Darwinism, in opposition to older views which are known as neo-Lamarckism. This designation is entirely incorrect, for Charles Darwin was just as firmly convinced of the fundamental significance of progressive inheritance as was his great predecessor Jean Lamarck and as is Herbert Spencer.

I had three times the pleasure of visiting Darwin at Down, and each time we discussed this important question upon which we completely agreed. I share the conviction of Herbert Spencer that progressive inheritance is an indispensable factor of the monistic theory of evolution and one of its most important elements. To deny it, as Weismann does, is to fly to mysticism, and it is better to accept the mysterious creations of separate species. The genesis of man affords innumerable illustrations of it.

When we regard the science of the genesis of man from the most general point of view, and bring together all the empirical arguments for it, then we may say to-day with perfect justice that the descent of man from an extinct tertiary primate chain is no longer a vague hypothesis, but an historical fact. Naturally this fact can not be exactly demonstrated; we can not point out the innumerable physical and chemical processes which in the course of a hundred million years have gradually led up from the simplest moner and the unicellular egg-form to the gorilla and to man. But the same thing is true of all other historical facts. We all believe that Linnæus and Laplace, Newton, and Luther, Malpighi and Aristotle once lived, although this can not be exactly demonstrated in the sense of modern physical science. We firmly believe in the existence of these and of many other heroic minds because we know the works they have left behind, and because we see the powerful influence they have had upon the history of civilization. But these indirect arguments have no more conclusive force than those which we have put forward for the vertebrate history of man.

Of many Mesozoic animals of the Jurassic period we know but a single bone, the under jaw, and Huxley has very finely explained the cause of this strange phenomenon. We all consider it settled that these animals had also upper jaws as well as other bones, although we can not certainly demonstrate it. Yet the "exact school," which considers the evolution of species as an undemonstrated hypothesis, must regard the lower jaw as the only bone in the body of these remarkable animals.

Let us now in conclusion take a hasty glance into the immediate future. I am entirely convinced that the science of the twentieth century will not only accept our doctrine of development, but will celebrate it as the most significant intellectual achievement of our time, for the illuminating beams of this sun have scattered the heavy clouds of ignorance and superstition which hitherto shrouded in impenetrable darkness the most important of all scientific problems, that of the origin of man, of his true essence, and of his place in nature. The incalculable influence of the science of the development of man upon all other branches of science, and especially upon culture, will bear the most blessed fruits. The great work which was in our century begun by Lamarck and finished by Darwin will for all time remain one of the most significant achievements of the human mind, and the monistic philosophy which we found upon its theory of evolution will not only powerfully further the perception of the truths of nature, but also their practical worth in the service of the beautiful and the good. This monism is, however, based upon the empirical data furnished by modern phylogenetic zoology.

THE LAWS OF ORIENTATION AMONG ANIMALS.[1]

By Capt. G. Reynaud.

It would seem that wild animals are devoted to a wandering life, and yet a careful observation of their habits shows that the fields, the woods, the plains, and the air are quite equitably divided among them, as separate districts. Each one of them lives within a domain whose resources he uses to the best advantage, and where, fearing the competition of his kind, he permits only a limited number of them to range. Thus among animals property is communal.

The extent of the domain varies, moreover, with the resources which it presents, the protection which it offers against every kind of danger, and especially according to the animal's power of locomotion.

This division of domain is in some measure a necessity of existence. Every animal that, by reason of defective instinct or for any other reason, attempts to escape from it is quickly exterminated by natural selection; driven off by his comrades with whom he strives for daily food, wandering haphazard in an unknown territory full of snares, he becomes an easy prey for the enemies of his species.

The instinct of orientation, which guides an animal back to his home, and consequently his habits, his food, his protection against danger, plays a prominent part in his life. To it he owes his individuality, the memory which attaches him to the past, and, up to a certain point, the satisfaction of his needs in the present.

We propose to study the mechanism of this orientation among animals. As the principal object of our study, we have chosen the carrier pigeon. A great number of facts observed by us for the first time have been grouped and classified. We have deduced, if not the law that controls, at least a theory that accounts for them. This theory we will now explain. All of its propositions are founded upon facts rigorously and scrupulously established or on experiments easy to reproduce.

I.

Just as occurrences seemingly casual, such as the distribution of bullets in a target, are subject to laws of which science has given us the

[1] Translated from the Revue des Deux Mondes, Vol. CXLVI, pp. 380–402.

secret, so in the capricious flight of a bird or the wandering course of a wild animal chance has, as we believe, no part.

The motive which determines the actions of the animal is the instinct of preservation of the individual and of the species. The animal is capable of a spontaneous activity when he is roused by necessity; it is very seldom that he performs an act that has no immediately useful end. Initiative[1] is not within his power, and when, in ants or bees, we think we have observed forethought for the future, we soon see that this supposed provision is nothing more than obedience to the momentary call of instinct; the animal accomplishes an action without foreseeing the result.

The search for food and sleep are the two poles between which the existence of an animal constantly gravitates. If, to utilize the resources of his domain, he is obliged to vary his course daily, the periodic need for rest yet brings him back to the same quarters. The lack of initiative leads him to always follow the same road to return to the same point. This is why the animal on his domain makes a number of trails which are interwoven in every direction; he acquires in this way a very complete knowledge of the locality; in the region where every little irregularity is familiar to him he is ready to move in every direction.

Necessity may force the inhabitant of one region to overstep its limits, in time of drought or famine, for example. Then he makes a rapid incursion into the neighboring territory, delays not a moment, but as soon as he has quenched his thirst or appeased his hunger returns in all haste to his home. In this second region, seldom fully explored, the animal knows but a limited number of trails, usually straight ones. If he is surprised there by a danger of any kind, he is much more exposed than in his own territory.

One example will show plainly the essential difference existing between these two zones. When a stag is attacked in his own domain by hunters, he begins by doubling, makes a thousand turns, and for a time throws his adversaries off the track. Soon again discovered, he sets out anew; pursued from shelter to shelter he finally "gets away" and plunges into the second zone, where the trails are straight. The chase then changes its character, and takes on a rapid pace which it did not have in its first phase.

The stag soon reaches the limits of the known territory and tries to return on his tracks and regain his own domain. Constantly driven back, pressed closely by the dogs, he again sets out, crosses the second zone, and then, entering the unknown territory, he is "off," running straight forward until he falls.

It is interesting to see how a stag acts who has been carried some distance in a cage and then set at liberty before a hunting party to be chased. The animal, cast on an unknown ground, does not try to

[1] An animal is by nature a slave to routine; when surprised by the hunter he does not invent a plan of flight, but makes use of trails over which he formerly passed.

double, but springs before the dogs and is off immediately. The chase presents none of the evolutions which we described above; it is nothing but a race between the herbivorous animal, who has on his side speed, and the carnivorous animal, who has endurance. From the condition of the animal and the speed of the hunting party one can determine beforehand the duration of the chase. We will not dwell longer on these facts so well known to hunters. It is, in fact, sufficient to go through a wood in Sologne, or in any other country abounding in game, to be convinced that the ground is traversed in every direction by trails which do not escape the experienced eyes of the poacher.

Birds also follow through the air roads invisible to our eyes, but which can be revealed by observation. The bird, like the quadruped, contracts the habit of always returning to the same point by the same route. We have watched for some time a group of pigeons that returned every day to the fields at the same time. In going, as in coming, they undeviatingly followed a line which we had marked out on the neighboring ground. We have observed the same regularity of route in the coming and going of two birds of prey.

The peasants know very exactly the points which mark the course of the migrations of birds, and turn this knowledge to account by hunting during certain seasons.

Similar observations have been made on fishes in the sea as well as in rivers, and the very exact information obtained is put to a daily use by fishermen.

We will not put further stress on an array of facts long since observed and known. We will limit ourselves to deducing from them a primary conclusion. In the air, on land, or in the water all animals follow routes definitely determined; their movements seem, therefore, to be subject to other laws than those of caprice or chance.

II.

The actions of animals are all dictated by a single law, which each one of them obeys in a different way. The animal is controlled by his environment. If he finds around his home an abundance of the necessities of life, he moves about but little and his existence is passed in a very restricted domain. In the opposite case he lives a very active life, traversing his domain unceasingly, extending its limits as far as possible and sometimes going beyond them. Each animal is thus led to contract habits which become peculiar to him and which constitute his individuality. He obeys the call of instinct, but he seems to have the choice of the means of execution, a certain liberty, while he is simply under the influence of his surroundings. It is necessary to bear this in mind before fixing those general laws to which the movements of the individuals of each species are subject.

It is a fact known by experiment for some time that an animal moving about in a territory familiar to him is guided in finding his way back to his home by all five senses working together. Always, in every species, one of the senses is more developed than the rest, and therefore plays a more prominent part in the act of orientation—sight for the bird, scent for the dog, etc.

If orientation within restricted limits is easily explained by the combined play of the five senses, it is not so as regards orientation in an unknown and distant territory. Let us cite an example: In order to lose a cat you put him in a bag and carry him by railroad a distance of 80 kilometers. Set at liberty he returns to his home. Though his sight and his local knowledge guided him constantly back to his home after his daily wanderings, he yet will not know how to make the same use of them on this occasion. His sight, were it excellent, could not be a great help to him, as the slightest obstacle, the most insignificant rise in the ground, would be sufficient to hide the familiar landscape. Is it, then, his sense of smell that guides him? In this case precautions seem to have been carefully taken to put this sense at fault. One fact, however, remains—we are going to try to explain it—the cat has easily returned to his home.

Let us take another example: The pigeon fanciers of Brussels every year let loose pigeons at Bordeaux. In preparation for this they make three successive releases, at increasing distances, between Brussels and Orleans, consequently towards Bordeaux, then after the release effected at Orleans, without further preparation, the pigeons are set at liberty at Bordeaux and they return to Brussels. Can we attribute their return to a memory of the locality, to a piercing vision? Let us admit that in the three preparatory flights the pigeons may have remarked certain prominent landmarks between Brussels and Orleans. At the time when they were let loose at Bordeaux, the elevation of the land, the rotundity of the earth, set limits to their vision, however piercing it might be. To see Orleans from Bordeaux the pigeon would have to rise several kilometers above the earth, which would be physically impossible.[1]

Let us cite another case: Some pigeons belonging to a pigeon fancier in Orleans had traveled in the direction of Reims. Some one conceived the idea of releasing them 500 kilometers out to sea beyond Nantes, without any preparation, and they almost all returned. In this example, as in those preceding, the return can not be explained by the working of any one of the five senses. It is therefore necessary to acknowledge the intervention of a distinct organ serving for orientation from a distance. Since the function exists, we are not illogical in supposing that there is, corresponding to that function, an organ which we will call the sense of direction.

We therefore admit that orientation near at hand is easily explained as the use of the five senses, and that orientation from a distance rests solely on the working of a sixth sense.

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[1] Pigeons rarely fly at more than 300 meters above the ground. Set at liberty from a balloon more than 2,000 meters high, they descend with a dizzy rapidity, letting themselves fall, and not resuming their flight until near the earth.

It has been objected that orientation from a distance or near at hand is always the same act, and that it is illogical, contrary to the established order of things, to see the same functions carried on by two distinct organs. But this objection is not well taken. It is quite frequent to see in nature the same function accomplished by very different organs.

The strawberry, for instance, is reproduced by means of the seeds formed by the foundation of the flower. It is also reproduced by means of runners that grow out from the plant, take root in their turn and abandon the fragile thread that holds them to the mother plant.[1] Close observation will enable us to cite many examples of the same sort. The hypothesis that a special sense comes in to take the place of the five original senses, whose range is limited, has in it nothing illogical.

III.

We will now study a number of interesting cases, seeking to deduce from them the mechanism of orientation from a distance.

First. During a hunt with greyhounds that took place in the forest of Orleans, a stag, not the animal hunted, was followed by some dogs; cornered in an angle of the forest he "went away;" the master of the hunt, seeing the mistake made, recalled his dogs and set them on the right track. But a poacher who had seen the stag leave the forest noted exactly the place where he passed out and lay in wait for him, feeling certain that the animal when he no longer thought himself threatened would return, by the next morning at the latest, and over exactly the same path by which he had made his exit. The result proved him right. The poacher had made use of the fact well known to the charcoal burners who live in the forest of Orleans. The stags and roebuck, finding almost everything they need for food in the forest, almost never leave it. When for any reason whatever they go out into the adjoining land they follow in return the same road they used in going.

The art of setting snares is founded on this observation. The snare prepared in the woods at a point presumably on the track of an animal, or even exactly at the spot where the animal has passed, does not necessarily entrap him. He wanders throughout the whole extent of his domain, often leaving one track to try new ones; while an animal which has ventured into strange territory will surely return shortly and pass at the same point at which he went out. If the snare be set at a point where his departure was observed he will surely be taken.

Second. The horse which passes twenty-two or twenty hours every day in the stable in semi-obscurity, his nose against the wall, can not be endowed with much instinct. All voluntary action is forbidden him, since he can only act in obedience to his master. His instinct is, if not atrophied, at least exceedingly diminished.

The stable is a permanent center of attraction to the horse, who finds

[1] The plant-louse has also several methods of reproduction.

there food and rest. When set at liberty he finds his way back to it with the constancy of the magnetic needle turning to the pole.

The horse knows perfectly the road back to his home. If in the course of a drive the reins are let to fall loose on his neck he will take this opportunity of returning to his stable. With the help of an excellent memory he knows the comparative length of the roads to be followed, and chooses without hesitation the shortest.

Suppose that the same horse is taken into a country of which he is ignorant. After a stay of some hours in a stable he develops the same attachment for his new home which he showed for the former. If in the first drive he is left to his instinct to find his way back it has been ascertained that he will follow the same road, reversed, by which he came, even if it is not the shortest.

Third. The carrier pigeon when set loose within a short radius of its home will return to its cote by the shortest way. If it is set at liberty some hundreds of miles from its home it follows in its return very exactly the line of the railroad by which it came. We need no further proof of this than the following fact.

In the season of the conventions of pigeon fanciers the inhabitants of Bapaume remarked the flight every Sunday of numerous bands of pigeons returning to their homes in the north of France, or in Belgium. We can not claim that Bapaume is exactly on the straight line that connects the different points from which the pigeons were let loose to their dovecotes scattered throughout the region of the north, from Dunkerque to Mézières. It was not merely choice that thousands of pigeons should pass every Sunday over the little city. Bapaume is only an insignificant point in the very extended zone which separates Belgium from the center of France. Moreover, from similar observations made at Amiens, at Arras, and all along the line of the route from Paris to Brussels, it was proven that the pigeons retraced in a contrary direction the road by which they had been taken to the place of release.

We might cite any number of observations of the same sort. For example, the employees of the Orleans railway have often told us of the passage to Arthenay, to Étampes, or to Juvisy of Belgian pigeons released at Poitiers, Angoulême, and Bordeaux.

We have deduced from these facts the following hypothesis, which we will call the "law of retracement." The instinct of orientation from a distance is a faculty which all animals possess in different degrees, of retracing a route over which they have once passed.

IV.

In the study of mathematics the method is often employed of considering a proposition as demonstrated, then stating it in the form of a problem and studying out the consequences. We will use this method here. Let us admit that the hypothetical law stated above has been sufficiently proven and let us make use of it to explain certain facts, inexplicable by any other means. Let us imagine that we are present at a release of pigeons. Many hundreds of birds coming from cotes in the same region are set at liberty at the same time. They set out together, separate to travel in two or three groups. Then as soon as they reach the horizon to which they are accustomed each flies straight to its own home.

A certain number of pigeons do not return, others come in on the following days. The owner merely registers the losses and notes the tardy ones without trying to discover the cause of the failure in instinct. In truth, how can we ask for the secret of a bird which, with one stroke of its wing disappears from our view. Its instinct is at fault; the bird must then wander at will, counting on chance to find its way home.

We can not agree to this proposition for the following reasons: The bird that has gone astray through a defect of instinct is still, nevertheless, not beyond the control of that general law of self-preservation which guides all its actions. On the contrary, it feels strongly the call of instinct which incites it to return to its own cote. It sees clearly the end, but the means of attaining it are for the moment at fault. It displays then all the voluntary activity of which it is capable, trying path after path successively. The law of retracement will permit us to follow it in its wandering course and to retrace its journey. When we have found out the secret of the lost pigeon we shall realize again that chance plays a very small part in the decisions of animals.

In 1896 we were present at Orleans when a number of pigeons from the cotes at Mons and Charleroi were released. The two bands of pigeons having by chance been set free at the same time, at two different points in the freight station, joined each other in the air and formed at their departure a single group. The weather was extremely unfavorable. Fog, rain, and contrary wind contributed to delay the return of the winged voyagers. One first mistake in instinct, easy to explain, was made at the outset. Two pigeons from Mons were taken in at Charleroi and three from Charleroi were received at Mons. Besides about forty pigeons did not return home on the evening of their release. They had, however, left Orleans together. The birds which first returned had pointed out to their companions the proper road and some of the latter had followed their guides blindly, even so far as to enter strange cotes.

But in Orleans an observer remarked that between 3 o'clock in the afternoon and 7 in the evening about thirty pigeons flew up and rested on the roof of the station. When night came we succeeded in capturing nine; five were from Charleroi and four from Mons. They were again set at liberty. This observation leads us to suppose that the thirty-two pigeons that returned to Orleans had all gone astray from the group released that morning. The next morning between 5 and 7 o'clock they all disappeared one after another toward the north; about thirty late returns were noted at Charleroi and at Mons on the same day. These goings and comings are all naturally explained by the law of retracement. Our winged travelers, although they formed a single band at their departure from Orleans, doubtless soon broke up into several groups; we have already observed that it was necessary for them to battle against rough weather. Now the carrier pigeons are not all in this respect equally provided. The little pigeon of Liège flies with extraordinary swiftness in ordinary weather. The full-plumed pigeons of Antwerp, endowed with considerable muscular strength, while they cannot vie with the Liège pigeons in ordinary weather, can, however, battle with a strong wind. It is then quite natural that our pigeons of different powers starting out together should divide up along the route according to their comparative strength. A pigeon from Mons, finding himself in the midst of a band of birds seeking Charleroi, follows them to their destination; then, having seen them scatter to their different homes he remains alone, lost on the roofs of a strange city. Mons is not far distant from Charleroi and the lost one need only rise into the air to see his own home. But he does not do so, for he has in previous journeys become accustomed to using only the sense of direction to find his way home from a distance; it never occurs to him to use his sense of sight. Retracing the road taken to reach Charleroi, he flies to the point in Orleans where he was set at liberty in the morning. Tired by the long journey he has made he rests for one night. The next morning he gets his bearings, finally finds the reverse of the journey taken two days before by the railroad and returns to Mons. The thirty-two pigeons who returned to Orleans on the evening of their release and the next day disappeared had very probably gone through an experience similar to this.

The example we have just cited is certainly very interesting. We have established our position with facts, and, when facts were lacking, with simple conjectures in order to explain the goings and comings of the pigeons. We have therefore in our conclusion, if not certitude, at least great probability. But we will now give a few cases more conclusive than the first.

A pigeon belonging to a fancier in Grand-Couronne fell into the garden of General M——, at Évreux. On the same day we had to go to Rouen. We took the lost pigeon with us and set him free in the station at Grand-Couronne, near his own cote. The pigeon took his bearings and flew off to Évreux, to the house of General M——. Again captured he was this time sent back to his owner by post. When released at his cote he no longer tried to return to Évreux. The pigeon, stopping to rest a minute and eat near the house of General M——, did not for an instant think of this unknown house as a new home. It meant for him only a point in the journey previously made and to be therefore the point of departure for his further flight. After some hours of rest he would have left to return again over the aerial path which had brought him to Évreux. He only thought of finding his lost cote.

We carried him to Grand-Couronne and set him free a few steps from his cote. But the sense of orientation from a distance, the sixth sense, was acting almost to the exclusion of the other five. The bird made his way back again, passed, as if hypnotized, in sight of his home—without seeing it,[1] and reached Évreux the point in the itinerary which he sought to reestablish.

His calculation was foiled, when led to the home of his owner and set at liberty he then knew where he was. The five senses, reawakened by stronger stimuli, rose supreme, and the sixth sense, having become useless, refused to act.

There is at Orleans a depot for pigeons where the birds are kept indoors. The pigeons which are shut in here and which come from the cotes of Paris and the north, live in a semi-obscurity and in absolute ignorance of what passes outside. When, after a month or two of confinement, they are to be released, the precaution is taken to carry them some miles from this transitory home, to which, moreover, no pleasant memory can attract them. We have ascertained that very often the pigeons know how to return to this house to which they do not even know the approaches. They come and rest on the roof, then after a very brief stay, take their bearings and disappear on the way back to their own home.

The law of retracement enables us to explain the action. Taken to the station of Aubrais, for instance, and released there, he will retrace his way and come to hover over the depot which represents for him the terminus of the road by which he was brought to Orleans. It is, then, from there that he will depart to reverse that journey whose memory has remained deeply graven on his mind.

We might cite a great many examples of the same sort to show that a lost pigeon always returns to the point where it was released. To convince ourselves of this it is sufficient to glance at the roofs of the stations of Paris, Orleans, Blois, Tours, Poitiers, Bordeaux, etc., where every Sunday, in good weather, hundreds, and sometimes thousands, of pigeons are set free. On Monday numbers of pigeons, lost the day before, return here. Having been unsuccessful in their first attempt to return to their homes, they will make a second and even a third attempt to find the right road.

When set free the day before, the pigeon took his flight, he flew as fast as possible from the place where he was released, a spot to which

[1] If sight is the principal means for orientation for the pigeon, those living in the cotes of the Grenelle quarter must be particularly favored since the building of the Eiffel tower. This is a prominent landmark easily seen within a radius of 200 kilometers around Paris. But upon inquiry we find the percentage of losses suffered during the training season from the pigeon farms around the Champ de Mars is exactly the same to-day as before the construction of the tower.

apparently no memory, no interest attracted him. If strong on the wing, he covered 400 or 500 kilometers, perhaps more, in the wrong direction—perceiving his mistake he knew, by some mysterious instinct, how to retrace his path and find again the point of his departure, the spot of his release, which he had hardly noticed in the morning. The combined work of the five senses can not explain such a return.

A lost dog behaves in exactly the same way. When, having been brought by rail to a hunting ground entirely unknown to him, and, having lost his way, he returns to the place where he last saw his master, and stations himself there to wait until someone comes to find him; or, even further retracing his way, he will follow back again the way by which he was brought and return to his home.

Let us cite one of a number of instances of this sort which have been reported to us by a trustworthy witness.

A young dog belonging to Mr. D——, a proprietor at Pont-Audemer, was carried to the station at Beaumont-le-Roger, and from there to a hunting ground situated between Goupillières and Fumechon. He disappeared during the hunt and in the evening returned to Pont-Audemer. Since he was by chance observed by certain railroad employees and gate keepers, who saw him pass, it has been possible to trace the road which he took. The dog returned first to the station at Beaumont-le-Roger, and then walked along the railroad to Pont-Audemer, passing Serquigny. To reach the station he had to walk away from home; he then walked along a road which made a considerable detour, several times crossing the Rille, while from Fumechon he could have reached Pont-Audemer directly by a much shorter route.[1]

The migrations of birds have been the subject of observations too well known for us to relate them. We will limit ourselves to explaining, with the aid of our theory, facts which have long been known.

The migratory bird is subject, like those of its kind that remain always in the same region, to the law of the domain. Only it has two domains, a summer and a winter one. It has been ascertained that the same swallows come every year to occupy the same nest, and the same region. The same observation has been made upon storks and upon many other birds.

When the time for departure is come, birds of the same species, inhabiting the same region, come together for the journey. Those that have already made the voyage take the lead and retrace the path by which they came. The younger birds, born since the last journey, confine themselves to following their elders, and when, some months later, it becomes time to return, these are able in their turn to follow in a reverse direction the journey previously made.

When the migratory bird, born in our country, who has never made

[1] When, on market day, peasants lose the dog which they have brought with them to the city, to seek him they go to the different places where their wagon has stopped and always find him again.

a journey, is for any reason not present at the departure of his companions, he does not go away. This is why woodcocks, wounded, and consequently unfit to undertake a long journey, resign themselves to remaining in our country another year. The same thing has been noticed of plovers, of curlews, of storks, and of swallows held in captivity at the time of the departure of their companions. Some of these birds endure the inclemencies of the winter climate; others, especially the swallows, succumb to them.

Thus, then, it is by means of a sort of tradition that the migratory birds transmit to each other from generation to generation the knowledge of the airy paths they follow. These paths once laid out are unchangeable.

The path of the quail that come to Provence from Africa, or of the woodcocks that alight in Jersey, is well known to the peasants, who capture them by thousands. To baffle their enemies it would be sufficient for the poor birds to change their path only a few kilometers. But they can not do it; they are fatally bound to this aerial route followed in their last journey, and they can not deviate from it or they will be lost.

Like other animals, fish also are districted: certain of them have, like migratory birds, two or three dominions which they successively occupy. To go from one to the other they emigrate en masse, following routes subject to the same rules as those we have explained for the migration of birds. The desperate war waged against them by fishers who know their habits has never decided them to change their route.

Our theory of orientation seems therefore applicable to animals of every species; it enables us to arrange properly and satisfactorily a number of facts observed and known for some time.

V.

We have demonstrated that the combined play of the five senses, whose range is limited, is not sufficient to explain orientation from a distance. This faculty is governed by a distinct organ, which we have called the sense of direction. The sense has its seat in the semicircular canals of the ear. Numerous experiments have, in fact, proved that any lesion which injures this organ results in immediate impairment of the faculty of orientation in the patient.

The semicircular canals of vertebrates are formed of three little membranous passages filled with a fluid called endolymph. They are independent of one another except at one point, where they have a common cavity, and open into a little sac called the utricle. They are situated, generally speaking, in three mutually perpendicular planes.

After the remarkable experiments of Flourens in 1834 and the autopsies of Ménière, their working was studied by Czermak, Harless, Brown-Séquard, Vulpian, Boetticher, Goltz, Cyon, Crum-Brown, Brewer, Mach, Exner, Bazinsky, Munck, Steiner, Ewald, Kreidl, and Pierre

Bonnier. To-day it is known that their function is directly connected with the faculty of equilibration and is entirely independent of audition. M. P. Bonnier, after having studied throughout the entire animal series the functions of the labyrinth and those organs which precede it, by comparing the data of comparative anatomy and physiology and verifying them by clinical observations, has been able to show that these organs subserve directly what he calls the "sense of altitudes," which furnishes the images of position, of distribution, and consequently of movement and of displacement in space.[1]

It is not yet exactly known what is the physiological excitant which puts in action the semicircular canals; awaiting further researches for the settlement of this interesting point, we will try to determine the method of action of the sense of direction. This way of procedure is moreover in no way illogical—in natural sciences, as in others, the knowledge of the effect usually precedes the knowledge of the cause.

An animal wandering in a strange territory follows on his return the reverse of the road, more or less winding, by which he came. When he reaches known territory he moves in a straight line to his destination.

The carrier pigeon, set at liberty at a distance of some 500 kilometers from its home, follows, in returning, the railroad which brought it; it is now guided by its sixth sense. Having in this way reached the known horizon, say 80 kilometers from its home, it no longer depends on its sixth sense, but goes by its sight straight homeward.

At other times when it reaches known regions the pigeon does not think of making use of its five senses, but follows its former path back to its cote. Sometimes it goes past it; thus we have seen pigeons returning from a long journey pass within 40 or 50 meters of the cote, go on and only return after an hour or two, having covered in this way, perhaps from 30 to 60 kilometers in the wrong direction.

If a common pigeon, accustomed to using almost exclusively its five senses, and a carrier pigeon broken to long voyages, are carried about 10 kilometers away from the cote, when they are successively released an interesting fact is noticeable—the ordinary pigeon, going by sight, will usually make its way much more rapidly than the carrier pigeon, who will find its way back carefully with the aid of its sense of direction.

From this fact we may conclude that the sense of direction does not combine its action with that of the five others. It begins to act in a zone where the other senses are inactive, and often continues to act in the known region to the exclusion of the other five senses.

It seems that it is not actuated by impressions received from the path followed and that it is in some degree a subjective organ. We

[1] We can only refer our readers to the researches of M. Bonnier on the Ear (Leauté Collection) and to a recent report to the Biological Society on the Sense of Orientation (December 11, 1897).

have made on this subject a very curious observation. When a basket of pigeons which have already performed journeys is carried by railroad, they manifest great agitation when they reach a station whence they have formerly been released, although they remained indifferent whenever they stopped at previous stations. Now, it will certainly be admitted that a pigeon inclosed in a basket. which in turn is shut up in a dark carriage, can not, from the noise alone, distinguish one station from another. Its sight and its other senses are of no use to it, since it is as completely as possible isolated from whatever passes outside, and yet it knows exactly where it is in respect to the point of its departure. We were right, then, in saying that an animal carried to a a distance possesses an entirely subjective idea of his situation independent of the surroundings through which he is for the moment passing.

Mythology relates how Theseus, penetrating the mazes of the labyrinth, held in his hand the thread given him by Ariadne. He could in this way go back on his own track and reach the entrance to the chasm. Does it not seem that the animal possesses likewise the thread of Ariadne, and unrolls it whenever he enters unknown regions?

Before we pass to a new course of thought. let us stop for an instant to consider an objection which naturally occurs to us. We have cited in support of our last deduction some observations made on the carrier pigeon. Since the organ of distant orientation has been developed by a wise selection in this interesting messenger, can we generalize and apply to other animals the remarks which concern it? We do not hesitate to answer such a question affirmatively. By selection man develops a certain faculty abnormally to the detriment of some other; he deforms the primitive type, often destroys the equilibrium of nature for his own profit. He can not, however, develop a new faculty; he must limit himself to only modifying the existing ones. Variation and heredity are, in fact, the only means which he can use to accomplish his purpose. We can not, therefore, discover in the carrier pigeon any trait which did not exist in the germ in its wild ancestor.

If a new example seems, nevertheless, necessary to confirm this theory, we will cite another interesting fact from the history of migratory birds. In 1883, on a dark night during a heavy squall, a flock of wild geese alighted at Clermont-Ferrand on the church of St. Eutrope and the neighboring houses. After a stay of two hours, the wind having lulled, the birds took up their interrupted journey through the air. Some of them, however, who had descended into the gardens or into the courts, did not succeed in taking flight. They struck against the walls or got entangled in the trees. Some were killed and others so badly wounded that they were picked up the next morning by the people.

The wild goose has not an eye formed like that of nocturnal birds. Deprived of sight by exceptional darkness, these birds did not, however, hesitate to set out on their journey, guided only by the organ of distant orientation. The sense of direction, a subjective organ, gave them the direction to be followed, pointed out the reverse of the path of the preceding season. Sight, an objective organ, would have put them on guard against obstacles; in the present instance it was of no use to them. This is why the birds on the church and on the roofs took up their way through the air without difficulty, while their companions, lost in a labyrinth of trees, walls, and houses, did not succeed in freeing themselves from these obstacles.

VI.

We have shown that an animal is restricted to a domain where he finds everything that is demanded for the preservation of himself and of his species. This domain, more or less extensive for the wild beast, is restricted for the pigeon, for example, to the four walls of his cote. In truth does he not find there, to use the apt expression of the fabulist, "good food, a good bed, and everything else?" On the other hand, if it is true that a knowledge of his locality is not absolutely indispensable to insure his return home, and the sense of distant orientation suffices to guide the animal, it will without doubt be admitted that it is possible to make a pigeon house movable and to teach its inhabitants to lead a wandering life.

Let us suppose that a cote is transported into entirely new surroundings without the least disturbance being made in the life of its inhabitants. They, set at liberty on their arrival, will perhaps wander away, but the law of retracement will insure their return. We have remarked above that a lost pigeon knows how to return to the point of his release which he has hardly noticed in the morning and to which apparently no pleasant memory, no interest, attracts him. For still greater reason the dweller in a movable pigeon house would attempt to retrace his journey. If he is taken to some distance and then released, he will go to find his home just where he left it. The movable pigeon house which comes into a new region will therefore render, to some extent, almost immediate service in the locality.

This new way of using the carrier pigeon, impracticable according to the ideas which have hitherto been held with respect to orientation, is only the strict application of our theory.

Interesting experiments have proved conclusively that faithfulness to his native cote can be reconciled with wandering life. A certain number of pigeons were born and raised in a wagon used as a pigeon house. They had no other home than this moving house. It was of little consequence to one of these pigeons whether its house stopped to-day in the bottom of a valley, to-morrow sought shelter in a forest, or stopped for a little while in the maze of houses forming a large city. If it were taken away from its cote to be released, it would not be guided on its return by the necessarily slight knowledge of the region around its carriage, but by the sense of direction, which would give it a subjective idea of its position in respect to its home.

Practice has in every case confirmed our theory. We have had occasions to make some interesting observations, and we will now cite certain facts which relate directly to our discussion.[1]

A pigeon carriage was stationed for twenty-four hours at Épernay. Its inhabitants were not set at liberty, while the pigeons of the neighboring wagons, after remaining quiet for two hours, were taken to some distance to be released.

The next morning the carriages were taken to Chalons, with the exception of the carriage from which the pigeons had not flown at Épernay. Those pigeons were distributed among the other carriages, which were exactly like the first in pattern. At Chalons the cotes were opened and these pigeons set free. Some of those which had made the journey from Épernay to Chalons in a strange wagon left for Épernay, and there found their wandering home. How did they succeed in tracing their way back from Épernay to Chalons, and in finding their carriage in a place of which they could know nothing? Only the law of retracement can explain this action. We have, moreover, repeated this curious experiment many times.

While a pigeon carriage was stationed at the Chateau of Morchies two pigeons went astray. They were found again at Bapaume, the last stopping place of the carriage. One was taken, the other escaped. Its course of flight was reported to us from all the places where its carriage had stopped. It arrived in this way at Houdain. From there it left for Évreux, taking up the reverse of a journey made some days before on the railroad. At Évreux, where the carriage had stopped for some months, we succeeded in capturing it. Is not the retracing of this journey step by step the best proof which could be given in support of our theory? By means of the law of retracement we can almost always determine the exact point at which to find our lost pigeon. We thus succeed in decreasing the number of losses which would otherwise be numerous and difficult to repair.

The return of a pigeon to a moving home is not an exceptional thing; we might cite many examples of the same sort borrowed from the history of birds.

The birds of prey which live in the forests of Argonne and of Ardennes or even in the solitudes of the Alps, find in spring in their native region everything that is necessary to their subsistence—young broods and game in abundance. But when autumn comes, when the game has grown strong and has learned to escape by flight from the pursuer, he

[1] Our experiments have settled one interesting point. According to M. Daresre, eggs shaken with some violence for a considerable time will not hatch out. We have proved that rolling over roads, over a pavement, or on a railroad, when the eggs are shipped, in no way alters the conditions of hatching. We may say with certainty that in a movable cote the pigeons hatch with the same regularity as their kindred in ordinary cote.

finds himself forced to abandon the domain which he has devastated; he emigrates to the plains and leads a wandering life, settling temporarily in such regions as offer abundant game. He picks out in the center of his hunting ground temporary shelters, to which he returns every evening until spring brings him back to the solitudes, where he builds his nest. What guides the bird of prey in this long expedition? Undoubtedly the sense of direction. We can not admit that the bird has a memory sufficiently lasting to retain for many months the recollection of all the irregularities of the ground which mark a course of many thousands of kilometers. All the bird's power of observation is in fact concentrated on one object—the chase. Topography is of no consequence to him. Like a registering machine set going at the moment of departure, the sense of direction notes automatically all the road covered by the bird in his pursuit of prey.

The cormorant and many of the fishing birds sometimes follow for many months the long routes of migrating fishes. Though lost in the midst of the sea, they know well how to return to their homes when their fishing is over.

Naturalists who have studied orientation have very wrongly noticed only one fact—the return to a single home. They have usually attributed this to a knowledge of the locality, founded on long observation. Such a theory gives no explanation of the facts we have just cited. Have we not shown that the law of retracement guides the animal when it wanders away from the known territory, brings him back to a temporary home, and sometimes, after an absence of many months, leads him back to his native region?

VII.

It would be interesting to know whether the theory we have just explained is applicable to man.

An animal's movements are regulated by the law of preservation, which assigns to him an imperative purpose, leaving him a restricted liberty in the choice of means. Man is actuated by the same law, but instinct is not the only determining cause of his action; he is also endowed with reason. While instinct points out to the animal only one course, reason points out to man many solutions; he chooses freely whichever seems best to him. He can even consider the promptings of instinct of no consequence; thus by suicide and Malthusian practices he may set himself in revolt against the law of preservation of himself and his kind.

We have attempted to prove that the action of orientation from a distance depends solely on the function of one organ—the sense of direction—which acts to some extent automatically. If a man who is trying to orient himself calls to his aid both reason and observation, the sense of direction, through lack of exercise, becomes atrophied. This is why a well-informed man, who estimates everything that he does, often finds his direction less accurately than a man whose intellectual culture is limited; he makes an act which should be in some measure mechanical and impulsive an act of reason. As a result of these considerations, savages, deprived of improved instruments and possessed of sharpened senses, can furnish us with more interesting facts than can civilized peoples.

A former military attaché at Pekin told us that when undertaking long hunting expeditions he took with him two Mongolians, who, after many days' journey, would lead him back to the point of departure. The confidence which he reposed in these guides was never deceived; they found again in the return the path followed in going. American Indians also seem to make use of the law of retracement when, after many weeks of absence, hunting in very distant regions, they return to their home. The nomads of Africa and Asia follow in their wanderings laws based to some extent on those which govern the migrations of animals.

These facts are certainly very curious, but one must not draw too strict conclusions from them; the primitive man knows, in spite of his intellectual inferiority, how to reason out what he shall do. It is consequently very difficult in analyzing an act of orientation to discern in it the part played by reason.

VIII.

We have vainly sought in the works of naturalists a theory which might explain satisfactorily the acts of orientation performed by animals. Many very interesting notes have been made on their habits; the life of certain ones has no further secrets for us. But when it becomes necessary to pass from effect to cause the observer usually takes the wrong side. Erroneously taking himself as a term of comparison, he asks what he would do to accomplish such and such an action proved instinctive in an animal. However, if an animal has not reasoning power he possesses senses whose power surpasses anything that we can imagine.

We know the famous experiment of the female peacock moth shut up in a box and set out at night on a balcony in Paris where representatives of its species were very seldom found. The next morning there were four males, doubtless from the neighboring forest, settled on the box. How did they know that 20 kilometers away they would find a female in the midst of Paris, where they had never before ventured?

When in the Pyrenees the hunters run down an ibex, it is useless for them to hide the entrails under a bush or in a hole; vultures appear from every direction, although but a few minutes before not one was visible on the horizon.

Such facts as these are inexplicable from what we know of the senses—of our own especially. The acts of orientation are not less extraordinary; therefore the observers who have remarked these things have tried to explain them by endowing the beast with the calculation and reasoning powers which we would use if we were in his position.

It is in this way that some pigeon fanciers attribute the return of the pigeons to a wonderful memory of the locality. In his daily sport the bird rising above his home will note the landmarks of the country, study their relative position, and will notice them in relation to his home, thus making a veritable triangulation of the country where he dwells. According to others, the bird does in time acquire a profound knowledge of the local magnetic currents. Such an hypothesis explains a mysterious fact by means of others still more mysterious. It has even been seriously suggested that a pigeon orients himself by the course of the stars.

We think that these fantastic theories should be rejected; an animal can not be a mathematician, a geometrician, an electrician, or an astronomer; and observers have been wrong to attribute any intellectual manifestation to a material action which only puts to use a very perfect organ. The animals most highly gifted in the art of orientation at a distance are not, in fact, the most intelligent, but those which possess the most powerful means of locomotion.

Such is the idea which has inspired us in the study of the mechanism of orientation. We have formulated a series of very simple propositions founded on observation and explaining a number of facts long known. It has been possible to draw from our theory many interesting inferences which experiment has confirmed. In expressing our opinion of this much disputed subject we hope to arouse discussion and incite to new researches which will doubtless lead us to a complete knowledge of the truth.

THE FRESH-WATER BIOLOGICAL STATIONS OF THE WORLD.[1]

By Henry B. Ward.

Away back at the beginning of the investigation of minute forms of life, which followed upon the invention of the microscope, or shall I say discovery, for it seems to have been historically an accident, the early students searched the ditches and ponds and lakes for the organisms which constituted the objects of their study. Anton von Leeuwenhoek, whose name is familiar to you as one of the most zealous early workers among microscopic objects, enriched science by a long series of new organisms of this character. Roesel von Rosenhof, whose careful investigations on various fresh-water animals, published under the title of Insect Diversions, are still standard sources of information concerning the habits and structure of these forms, together with Swammerdam, Trembley, O. F. Müller, and a whole host of others devoted their attention almost exclusively to the fresh-water fauna. But this movement seems to have culminated with the appearance in 1838 of Ehrenberg's famous volume The Infusion Animalcules as Complete Organisms.

Extended investigations had already impressed zoologists with the richness of the marine fauna. Numerous animal groups of common occurrence in the sea were apparently entirely wanting in fresh water and the astounding richness of the subtropical and tropical oceans with which the European investigators came early in contact on the shores of the Mediterranean and in the expeditions to the new lands of the Tropics entirely overshadowed the life that had hitherto been found in pond or ditch. It is in my opinion also no small factor that many of the marine forms which were brought to the attention of scientists were dazzling in their beauty of form and in the brilliancy of their coloring. The quieter, more unassuming forms of lacustrine life in temperate regions could make no corresponding impress on the minds of the observers. So the scientific world went to the seashore for study and everywhere along the coast of Europe, and even in the islands of the Tropics were to be found the vacation resorts of scientists.

[1] Annual address of the president before the Nebraska Academy of Sciences at Lincoln, November 25, 1898. Printed in Science, April 7, 1899, Vol. IX, No. 223.

This diversion of attention from the study of fresh-water life was undoubtedly aided by the fact that fifty years ago all centers of education and investigation were comparatively close to the ocean, and so it was easy for the scientist to reach the point where, as he had learned from the reports of others, life was most abundant and varied and at the same time appealed to his æsthetic sensibility as nothing did that he saw about him. The concentration of interest on the life of the sea led to the foundation of marine stations, among which that at Naples was the first in point of time, as it always has been and is to-day first in point of strength. But the development of educational institutions through the large continental areas and the limitations which their location imposed upon investigators connected with these institutions, together with the natural efforts of man to find a field for investigation which should afford him a better chance than already overcrowded territory, have led again to the investigation of fresh-water life. So it was that Fritsch, in Bohemia, entered upon lacustrine investigation as early as 1871, while about the same time Forel, in Switzerland, was carrying on those studies published between 1874 and 1879 in a series of papers on the Fauna of the Swiss Lakes, culminating in the crowned memoir of the Academy of Sciences on the Abyssal Fauna of the Swiss Lakes, that brought to the knowledge of the scientific world a hitherto unsuspected type of existence and offered a new and enticing field for investigation.

It was also in the same year, 1871, that Stimpson, one of the enthusiastic members of the old Chicago Academy of Sciences, conducted some dredging expeditions in the deep water of Lake Michigan, while about the same time Hoy, Milner, and Forbes entered upon investigations at other points on these same lakes. The Chicago Academy and its collections, together with valuable manuscripts of Stimpson, were destroyed in the great fire. The United States Fish Commission, under whose auspices the work of Hoy and Milner was inaugurated, did not pursue further the investigations of the lakes, and for years Forbes was the only investigator who occupied himself in this country with the study of lacustrine life. To his work and influence we owe beyond a doubt in our own country the awakened interest in limnobiology, and under his direction also was established the first general fresh-water biological station on this continent, of which more in another connection.

The impulse toward the investigation of fresh-water life which was inaugurated by these men gradually attracted to itself workers, slowly at first, but approximately a decade ago with a sudden start the ranks of such were rapidly filled up. An enormous number of ponds and lakes, large and small, scattered over the surface of the continents, afforded an almost unlimited field for investigation, and many early studies were, to say the least, decidedly desultory. There were few workers who were content to confine themselves to a single locality, or to a well-defined problem. A scanty collection was made to serve as the basis of a faunal list supposed to characterize the body of water in question, and the enumeration of species was regarded as the ne plus ultra of many investigators.

Like the spiritless systematic zoology, which, in the work of many minor investigators, followed upon the example set by the great Linnæus, so lacustrine investigators in considerable number were apparently satisfied to describe, as the results of brief sojourns, the fauna of a lake or lake region, or, perhaps, even from a couple of vials of material collected by some rich patron in the course of a journey around the world, to discuss monographically the fresh-water fauna of the Fiji Islands, for instance. Under such circumstances there could be no biological study. The chief aim seemed to be to cover as much ground as possible in a short time. And what Lauterborn said five years ago is even truer to-day in the light of our more extended experience: "For the question as to the distribution of organisms, the methods so cherished even up to the present day of fishing in the greatest possible number of lakes (which recalls, in many respects, the chase after new summits on the part of our modern high climbers—*Hochtouristen!*) really have only limited claim to scientific value, since through them but a very incomplete picture of the faunal character of a water basin can be obtained."

The earlier investigators whose work has already been mentioned, Fritsch in Bohemia, and Forel in Switzerland, had been pursuing a single problem or investigating a limited locality for nearly twenty years, and they were among the first to emphasize the necessity of a modification of the prevalent tendency and of a more formal character for lacustrine work, if valuable scientific results were to be expected from it. Forel was the first to publish, in outline, a plan for the precise formal investigation of a body of water, in which emphasis was laid upon the necessity also of continuous and extended investigation before satisfactory conclusions could be hoped for. This programme has suffered some modification in detail at the hands of various students, but in its general features remains the aim and desire of workers everywhere. With the appreciation that such work must needs be formal, continuous, and extended, came naturally the desire that stations of a permanent character should be established at various points for the realization of the idea. And the first of these that were founded were of a general character, concerned with the biological investigation of water as a problem of general scientific interest and importance.

But almost immediately other influences made themselves felt which have led to the extension of the general idea along particular lines of economic importance. Improved methods of fish catching and larger demands for fish food had brought various countries to the point where the drain on this kind of food supply was becoming very evident. The fish were being destroyed more rapidly than natural means could restore their numbers, and it was felt that something must be done by governmental agency to replenish the depleted waters. The first expedient of collecting and keeping under satisfactory conditions large numbers of fish eggs until they should be hatched and the young fry distributed through the waters was not so successful as had been hoped. The problem was too large to be attacked in such a superficial manner, and the further knowledge, which it became clear was absolutely necessary for proper handling of the question, must needs be sought through some means for the investigation of the conditions and determination of the steps necessary for the solution of the problem, and for carrying into effect the measures which might afford the desired relief. This led first in Europe, to be sure, in connection with private enterprises for fish culture, to the establishment of biological experiment stations with the fish hatcheries, very much as chemical laboratories are now necessary adjuncts of various manufacturing interests, or agricultural experiment stations are connected with the higher development of agricultural possibilities. There is, however, a still further demand which has led to the formation of institutions of the general type which we are considering. The water supply of our cities has always been a serious problem and one of increasing interest in connection with crowded conditions in the more thickly settled countries of the world, and the biological examination of the water, undertaken of necessity, has led to the organization of biological laboratories connected with the water systems of great cities, both on the Continent and in our own country.

Having thus discussed the causes which have led to the establishment of limnobiological stations, we may now consider, briefly, the types which they present, and the particular results which may be expected from a given sort. Of course all probable variations may be found, and it is difficult to make any classification which is complete or even just, and yet for convenience we may divide these enterprises into a few great groups, recognizing the fact that certain of them do not belong singly to any one class, but combine features of different types. But before outlining this classification, let me say that I do not regard the existence or nonexistence of a building or structure devoted to the purpose of investigation as a necessary mark of a biological station. Some of the most valuable contributions to general and special questions in this field have come from investigators or groups of investigators who have had no abiding place, while, on the other hand, stations well equipped with buildings and apparatus have in some instances, so far as can be ascertained, contributed nothing even after several years' existence, to the progress of scientific knowledge. Material equipment is valuable, and in general, conduces to better results, and yet it is the results themselves which finally determine the character of any enterprise and the position which it should hold it the esteem of the world.

For the purposes of this discussion I propose dividing biological stations into, first, individual resorts; second, periodic resorts, and third, permanent stations. Individual resorts are such as are characterized by the work of one or more individual investigators, working for the most part independently, and solving their problems by virtue of their individual investigations. There are, of course, a large number of such places where some investigator has made sporadic or single efforts at the determination of the faunal character of a water basin, or has paid a number of occasional visits to such a locality for the same purpose. On the whole, these stations have accomplished comparatively little, although we find striking contradictions of the general statement.

They may be, however, of a more regular and definite character, and some of these personal investigations have been most valuable in extending our present knowledge of fresh-water life. It may be noted here that the permanence or regularity which contributes to the success may be either in the location of the point at which the investigations are carried out or in the definiteness of the purpose which is followed; thus Imhof's studies on the pelagic fauna of the Swiss lakes were permanent in their value, and Zschokke's investigation of the biological character of elevated lakes carried on at numerous points in the Alpine chain has resulted in fundamentally important contributions to the lacustrine fauna of high altitudes. Yet neither of these was at all confined to a single locality, though limited by a definite purpose.

Periodic resorts are those to which groups of individuals are accustomed to go for a certain portion or season of the year, most commonly for a vacation period, in accordance with which they are denominated summer or winter laboratories. The larger number of the investigators tends toward securing a more complete idea of the biological problem as a whole, so that the results obtained from such stations are of evident value. Yet at the same time it must be noted that they are distinctly inferior even to many individual resorts, since during the larger portion of the year no investigations are carried on and the results obtained are necessarily partial and incomplete in their character, and hence unavailable for the decision of the broader and more fundamental biological questions.

Permanent stations are those at which operations are conducted throughout the entire year by a definite corps of observers. The continuity of their work renders their results valuable for the decision of general biological problems, and at the same time the permanent force which, in part at least, is indispensable in such an institution implies that the undivided attention of the observer is devoted to these problems; from this we may then expect justly that greater results will be obtained than in the case even of the best of individual resorts, since the investigators who are carrying on operations at these are, so far as I know, without exception connected with educational or scientific institutions which demand at least a part of their time, and to that extent divide their interest and their energy.

It is furthermore clear, from what has been previously said, that such permanent stations are of two distinct classes. First, those which may be denominated general, even though their work is of the greatest value for special purposes, and, second, those which are distinctively technical by virtue of their association with specific enterprises.

It is but natural that the different continents are very unequally represented with regard to the number of stations that have been established upon them, and with respect to the knowledge that has been gained in reference to their fresh-water fauna and flora. Thus, our knowledge of the Australian fresh-water fauna is confined at present to the report of collections made by travelers, and to the investigation of specimens raised by Sars from dry mud which had been sent to him. Of Africa we know that fifteen years ago an expedition brought word from Lake Tanganyika that while rowing across its waters they encountered swarms of jelly-fish, while many of the gastropod shells which were brought back with them showed in an equally striking way their marine character. These reports have been confirmed by an expedition that has just returned, and the strikingly marine complexion of the fauna of the lake can hardly be doubted. This appears all the more strange since collections made at Lake Nyassa, which lies decidedly nearer the sea, show nothing but what is specifically lacustrine. Such facts point, of course, to the importance of the African fresh-water stations of the future.

From various lakes of Asia, all the way from Ceylon to Siberia, numerous more or less extensive collections have been made by travelers, though there is hardly anything sufficiently extended to warrant the statement that a station has been located, even for a limited time, at any point, especially since most of the collections have not been investigated by men who had made them, but have been turned over as alcoholic material to European investigators for study. We do know, however, that Lake Baikal, which is situated almost in the center of the continent, harbors a rich molluscan and crustacean fauna that is characteristically marine in its form, and is further distinguished by possessing many sponges clearly of marine type, and at least one species of seal (Phoca), a genus which is typically oceanic. A discussion on the meaning of these features lies far from the purpose of the present paper, but certainly such facts do point out most strikingly that the field of limnobiological investigation is not lacking in topics of extreme interest.

From South America reports concerning the fresh-water fauna are perhaps most scanty of all. Frenzel, a German investigator, who lived many years in Argentina, has published some interesting studies made while there on the Protozoa; a few isolated notices of the lacustrine fauna from various regions complete the list.

From these statements it is apparent that the work done thus far outside of Europe and North America is exceedingly limited, and that for our judgment of the results in formal limnobiological investigations we must look to the laboratories of these two continents. Among all European countries, Switzerland has furnished perhaps the greatest number of investigators and stations for limnobiology, together with the most extended and valuable results, although even yet there is not in that country, so far as I can ascertain, a building exclusively devoted to the purposes of this investigation. First and foremost among these investigators may be mentioned Forel, of the University of Lausanne,[1] to whom reference has already been made. His investigations have been carried on for more than thirty years on Lake Geneva; to him we are indebted for the first knowledge of the abyssal fauna of a fresh-water lake, for the first extended programme and plan for the investigation of such a lake, and for the first effort toward the realization of such a plan, which finds its full expression in his "Lac Léman," a monograph at present in the course of publication; the volumes which have appeared thus far treat of physical, chemical, and meteorological conditions on the lake, and are to be followed by others which will complete, with the flora and fauna, the entire limnologic investigation. The series will make a magnificent and permanent contribution to lacustrine investigation, and will serve as a model for the work of all times.

The work of Zschokke, professor at the University of Basel, has been directed, as already mentioned, toward the elucidation of the faunal aspect of elevated lakes. It has been carried on through many years at different points, including the lakes of the Jura to the westward, as well as those in various regions of the Alps proper, and his papers on the fauna of elevated lakes contain the only general statement of the problem, as well as of the characteristic features of such localities, that has yet appeared.

Lake Constance has been the scene in recent years of the work of numerous investigators under the guidance of an association for the investigation of the lake, which has its headquarters at Lindau. The published accounts of these investigations have thus far been preliminary in character, and I am unable to learn whether there is a building devoted to the purposes of investigation and whether the work is carried on throughout the entire year. This lake was the scene of early investigations by Weismann in 1877, and the present work, which was inaugurated about 1893, is under the direction of Hofer, of the University of Munich.

At present Switzerland is the scene of the most extensive scheme for lake investigation which has been entered upon anywhere. Under the leadership of the Limnological Commission appointed by the Swiss Natural History Society all efforts in lacustrine work are to be directed and unified; methods, problems, and localities are to be studied in the most thorough manner and the results are to be published by the

[1] In a sense the laboratory of the university, which is located near the shore of the lake, is the building of the station, as in Wisconsin, mentioned below.

society. The work on Lake Lucerne and Lake Constance is already far advanced, and other lakes are under preliminary examination.

To Bohemia belongs the honor of having had the first definite building for lacustrine investigations in the form of the Bohemian Portable Laboratory, which was constructed in 1888, under the direction of Professor Fritsch, of the University of Prague. Reference has already been made to the early work of this investigator, who, in 1871, reported to the Academy of Sciences in Prague the results of his investigations on Black Lake, a small body of water in the Bohemian forest, with reference to the distribution of animals according to the depth of the water and their relation to the shore. These investigations, which were extended to other lakes in the same year, are, I believe, the first, at least to be recorded, that were carried out in this way. It was, however, in 1888 before Fritsch succeeded in obtaining funds for a small portable zoological laboratory having some 12 square meters of floor surface. The station remained at its first location four years, and was replaced by a permanent structure, when it was removed to another locality. This portable laboratory has been regularly visited at brief intervals of time by the director and his associates in the three localities at which it has been situated during the last ten years, and the contributions from this work constitute most valuable studies on the lacustrine biology of Bohemia.

In Finland there exists the laboratory of Esbo-Löfö, on one of the small islands which, though primarily a marine station, is so favorably located with reference to bodies of fresh water that it has devoted a considerable portion of its energy to the investigation of the fresh-water fauna with valuable results. This laboratory, which is closely allied with the zoological museum of the University of Helsingfors, has been maintained since 1889 under the direction of Dr. K. M. Levander. Its contributions are published in the Acta Societatis pro Fauna et Flora Fennica. One of its workers, Dr. Stenroos, has for several years individually visited Lake Nurmijärvi, one of the small inland lakes with which Finland is so plentifully supplied; it is a body of water which, though it is about 2.5 kilometers in length by 1 in width, has a maximum depth of only 1 meter. He has given us a very complete faunistic and biologic study of its life.

Russia has recently established a station on Glubokoe Osero, or Deep Lake, in the province of Moscow, under the patronage of the Imperial Russian Society for Fish Culture. The station is under the direction of Professor Zograf, of Moscow University, whose contributions to lacustrine investigation have been made known, especially in a paper on the lake regions of Russia, from the biologic standpoint, which was read before the International Zoological Congress in 1893. I infer that the station is a permanent one, and probably of a technical character, although precise information on these points has not been obtained. Hungary has maintained for some years a lacustrine station on Lake

Balaton, one of the largest fresh-water bodies of Europe, having an area of over 266 square miles, though its maximum depth appears to be only 11 meters. It is surrounded by enormous marshy areas, which give thus varied conditions for the development of life. Several parts of the report on these investigations have already been published.

In France there exists a lacustrine laboratory near Clermont-Ferrand, which was organized in connection with the zoological laboratory of the university of that name in 1893. The reports from the station are recorded in the Revue d'Auvergne. At Paris, Drs. Richard and de Guerne have investigated collections from a large number of lakes not only in France and neighboring countries, but even from Algeria, Syria, the Azores, and other points, and have published valuable contributions on the distribution of fresh-water crustacea, as well as systematic monographs of various groups.

In Germany all types of stations are represented, as might be expected from the importance of scientific study in that nation. Individual investigators, not a few, have examined various lakes or lake regions, most prominent among them being undoubtedly Apstein, whose studies on Holstein lakes have extended over many years, and whose work on fresh-water plankton is the first general statement of the problems and of the methods used by Hensen in the investigation of marine life with such success, and by Apstein first applied to lacustrine investigation. Probably the best known fresh-water station in the world is that on Lake Plön, also in Holstein. This was the first permanent general fresh-water station to be established in the world. It owes its inception to the energy of its present director, Dr. Zacharias, whose plan was to establish for fresh water an institution similar to the Naples Marine Biological Station. The station opened in 1891, and since that time it has been in continuous operation, and has afforded opportunities for investigation to a large number of scientific workers, both German and foreign. It is the most pretentious of all fresh-water stations, having a building two stories in height, with numerous laboratory rooms, and is equipped with abundant apparatus for collecting and investigating. From it has been published yearly since 1893 a volume of studies, and the director has also contributed largely to other journals on limnologic problems. Two other stations in Germany owe their inception to the fishery problem, and have for their purpose more particularly the investigation of those limnologic questions which deal particularly with the life of the fishes. One of these is located at Müggelsee, near Berlin, and is conducted under the auspices of the German Fishery Association. The other, at Trachenberg, is under the auspices of the Silesian Fisheries Association. Both have made important contributions to the biological questions concerned in fish culture. A portable station has also been maintained since 1886 by the University of Königsberg.

All the North American stations which are known to me lie within the limits of the United States, and they represent all the various types of such institutions. A considerable number of workers have reported isolated investigations of lakes in all parts of the country from Maine to California. Among the most important of these occasional observations are those made by Forbes on the fauna of elevated lakes in the Rocky Mountains. The observations which he has recorded were made in the course of a preliminary investigation of these lakes by the United States Fish Commission, and constitute the only information on record with reference to the lakes of the country west of the Missouri River. There are but two localities which may be listed, however, as individual resorts sufficiently regularly visited to entitle them to more particular mention in this place. Green Lake, in Wisconsin, has been carefully studied by Professor Marsh, of Ripon College, and his work has yielded valuable information with reference to the vertical distribution of the crustacea and with regard to the deep-water fauna of the lake. Here he was able to confirm the observation of Stimpson, on Lake Michigan, that there are found in the deep waters of our large lakes crustacea of a purely marine type. At Lake Mendota, in Wisconsin, on the shores of which is located the State University a careful investigation, extending over a very considerable number of years, has been carried on by Professor Birge, of the university. The results which he has obtained with reference to the distribution, both vertical and seasonal, have been published by the Wisconsin Academy and are not only the most extensive, but beyond all comparison the most precise investigation which has been made on this problem. Of course, in one sense, this station has no building, but the scientific laboratory of the university, standing within a stone's throw of the shore of the lake, affords opportunities which are not surpassed at any fresh-water station in the world.

The lake laboratory, founded in 1886 at Milwaukee, Wis., owed its inception and support to the liberality of E. P. Allis, jr.; it was unique in that a group of investigators were kept at work for years under an environment ideal in equipment and opportunity, and were afforded every advantage for the prosecution of their investigations, so that it combined the advantages of the individual resort with those of the permanent station. One need only mention the work of the founder on the lateral line of fishes, and the papers of Ayers, Patten, Whitman, and others, to show the influence it has exercised on the development of biological work in our country. And it should not be forgotten also that we owe the foundation of the Journal of Morphology and much of its support for years to the same generous patron. The lake laboratory has been temporarily closed during the illness and absence from this country of its founder; there is a general hope that it may soon be reopened.

Quite a number of periodic resorts of the type of summer laboratories are to be found in various parts of the country. Some of these are merely summer schools, such as the Biological Laboratory of the Chautauqua College of Liberal Arts, on Lake Chautauqua. Others are both for teaching and for investigation, while only a small number are exclusively devoted to the investigation of limnologic problems from one standpoint or another. The University of Minnesota maintained in 1893 at Gull Lake, near the center of the State, a laboratory for summer work by members of the university, and for the prosecution of the natural history survey of the State under the direction of Professor Nachtrieb, of the university. The State University of Ohio has conducted, since 1896, a lake laboratory at Sandusky, on Lake Erie. It occupies one of the State fish hatcheries, and is supplied with the necessary apparatus by joint action of the university and State fish commission. Its purpose is to afford a convenient point of work for the members of the university, and also to aid in the prosecution of the State biological survey, which is being carried on by the Ohio Academy of Sciences. The immense stretches of shallow water, marshy regions, and protected areas, together with the varied character of shore and the open lake within easy reaching distance, serve to make Sandusky perhaps the most favorable place on Lake Erie for the study of the fresh-water fauna and flora. The station was closed a year ago, owing to the death of the director, Professor Kellicott, but has since then been reopened under the charge of Prof. Herbert Osborn.

In 1895 the University of Indiana opened a biological station on the shore of Turkey Lake, in the northern part of the State, under the direction of Professor Eigenmann, of the university. A constantly increasing number of students has visited the station each summer. The majority of them have been teachers of the State engaged in the prosecution of work to equip them for their teaching, but others have also assisted in carrying out a general survey of the lake fauna and in the collection of material to illustrate annual variation and associated problems. For comparison, collections have been made from adjacent lakes connected with other water basins. In the coming year the station is to be moved to the shores of Winona Lake, some 18 miles from the present location, where two buildings are to be constructed for its use by the Winona Assembly. The contributions from the laboratory have been published in the proceedings of the Indiana Academy.

For a number of years the Michigan fish commission maintained a force of a few scientific investigators and assistants in conducting a biological examination of the inland lakes of the State, under the direction of Professor Reighard, of the University of Michigan. In 1893 it was determined to transfer the seat of operations from inland waters to one of the Great Lakes, and by virtue both of its convenient location and of its importance as a famous spawning ground of the lake fish, which had, however, almost ceased to visit it, Lake St. Clair was decided upon as the locality for the first year, and the laboratory was located on a small bay at the northwest shore of the lake. The party consisted of half a dozen scientific workers, whose attention was exclusively devoted each to his particular field, and the results of the survey were published in bulletins of the Michigan fish commission. In 1894 the station was moved to Charlevoix, a famous fishing region on the eastern shore of Lake Michigan, and owing to the absence of Professor Reighard in Europe I was requested to take charge of the work. The scientific force and the methods of work were similar to those of the preceding year, but the location brought us in contact not only with shallow waters, but also with the deeper regions of Lake Michigan, and the party made investigations and collections of a precise character in the deepest fresh water which has as yet been investigated by such methods. The results of the summer's work were published in a bulletin of the commission. Unfavorable financial conditions compelled the suspension of the work on the part of the Michigan fish commission, but American investigators owe much to the impetus which has been given to such work through their agency.

For many years the United States Fish Commission has been urged to establish on the Great Lakes a biological station similar to that which has long been maintained on the ocean, at Woods Hole, Massachusetts. Finally, a year ago a preliminary survey was undertaken with a view to deciding the advisability of such a movement, and Professor Reighard was requested to assume the leadership of the enterprise. The United States Fish Hatchery at Put-in Bay, a small island in the center of the west end of Lake Erie, was selected as the seat of operations, and a party of scientific workers spent two months in studying the fauna and flora of the adjacent waters. It is to be hoped that this work may develop into a permanent experiment station on the Great Lakes.

Among permanent American stations of a technical character the Experimental Filter Station of the Massachusetts board of health, located at Lawrence, is the best known, as it is also perhaps the most famous of its kind in the world. It has been in continuous operation since 1887, and has conducted extended experiments on the biological examination of drinking waters. The methods worked out in connection with them are now standard for such purposes. Similar technical laboratories are in operation in Boston, Lynn, Worcester, and other cities; but in most of them the biological examination of waters is only a secondary function. The Mount Prospect Laboratory, organized recently in connection with the Brooklyn waterworks, and placed under the direction of Mr. G. C. Whipple, whose contributions to limnobiologic questions are well known, is more particularly devoted to the investigation of questions connected with the character of the water supply. Numerous samples taken from all the sources of the city's supply are subjected each week to physical, chemical, microscopical, and bacteriological examinations, and the quality of the water controlled thereby, since the reports made to the chief engineer serve to guide him in the choice of the sources from which the water is drawn. The results of such studies are also of great importance in general limnologic questions.

The University of Illinois was extremely fortunate in having associated with it, by statute, a State laboratory of natural history, which has been engaged for many years in a natural-history survey of the State. Under the direction of Professor Forbes, whose pioneer work on the lake fauna has already been noted, particular attention was paid to such questions as the food of fresh-water fishes and the distribution of various groups of fresh-water organisms, so that both by preliminary work and in the person of its director the State laboratory was peculiarly fitted for the successful inauguration of an Illinois biological station, which became possible under State grant in 1894. The laboratory secured a permanent superintendent in the person of Dr. Kofoid a year later, and work has been carried on continuously by a permanent force since that date. The laboratory was unique in its inception, since the director, Dr. Forbes, conceived the idea of locating it on a river system rather than, as all previous stations, on a lake, and it was not only the first in the world, but is yet the only station which has peculiarly attacked the problems of such a system.

The Illinois River and its dependent waters were selected as the field of operations and Havana, Ill., as the center of work. The river here presents in its cut-offs, bayous, shallow, marshy tracts, sandy areas with wooded margins and regions of spring-fed waters, and with the enormous extent of land covered at high water, a variety of conditions which it must be confessed could not be surpassed and hardly equaled elsewhere. The abundance and variety of the flora and fauna, both in the higher and lower forms of life, demonstrate the good judgment exercised in the choice of locality. A noteworthy feature in the equipment of this station, and, so far as I know, one that is unique, is the floating laboratory, which enables an easy transfer of operations to other points, where work can be carried on for comparison or contrast, with equipment and environment as satisfactory as that which exists in a permanent building, but with the flexibility and facility of movement which characterizes field studies. The work has been conducted uninterruptedly for more than three years, and the results include studies on the insects and their development, on the earthworms, on the Protozoa and rotifers, on various groups of crustaceans and general investigations on plankton methods, and on the distribution of the plankton, while some work has also been done on the plant life of water. These studies have been published in the Bulletin of the Illinois State Laboratory of Natural History.

Let us consider, in conclusion, the function and future development of these institutions. It is perfectly clear that the work of the different types of fresh-water stations will vary somewhat with the class, and Zacharias has outlined carefully the differences in the work of the fixed and of the movable stations. But these are, after all, minor differences. All stations, whether fixed or movable, have really three objects—teaching, investigating, experimenting—objects which may be subserved directly or indirectly, or in both ways, by each one of them. It is unquestionably true that the tendency within recent years has been to make the university-trained scientist a laboratory man, unacquainted with work out of doors and among living things. This has reacted unfavorably upon his teaching powers, and thus indirectly upon the entire school system. Not that subjects in natural history are not better taught in our secondary schools than they were twenty years ago, when, in truth, they were hardly taught at all, but that the naturalist to-day is not trained as an outdoor observer and is little capable of handling himself and his work in a new environment. As Forbes says, "It is, in fact, the biological station, wisely and liberally managed, which is to restore to us what is best in the naturalist of the old school united to what is best in the laboratory student of the new." Thus, both through the influence of the investigators in the case of those stations which do not carry on directly any educational work and through the teaching of those which do conduct summer instructional courses, new life will be instilled into the teaching of natural history throughout our country.

In the second place, the fresh-water station is a center of investigation with all its stimulating effects on the individual thus brought in contact with problems of nature and efforts for their solution, and in the contributions to the advancement of knowledge which are the fruits of a careful work on the part of its attachés. All that has been said of the advantages of marine stations applies equally well to fresh-water laboratories, together with the added advantages that their accessibility brings these advantages to considerable regions which would otherwise be entirely without them by virtue of their distance from the sea. It is unnecessary that I should emphasize further this phase of the question or dwell upon the greater simplicity of biological conditions in fresh water over those which exist in the ocean. These factors have been forcibly presented by many writers.

Finally, the fresh-water station should be above all things an experimental one, and in this direction the most valuable results are to be looked for, both from the general scientific and from the technical standpoint. To the scientist, this needs no demonstration; but it is essential that the importance of such work, especially for fish culture, be more widely understood. The advance in agricultural methods in the United States is unquestionably due in large part to the development of a splendid series of agricultural experiment stations in which agricultural problems have been subjected to intensive experimentation. Contrasted with this, conditions in fish culture present almost the opposite extreme. Fish eggs have been hatched in enormous numbers, but what is known of their subsequent history or what has been done to insure the safe development to maturity of the fish? Present methods have reached their limit and the subject must be attacked from a different standpoint. Fish culture should receive by the liberality of State and nation the same favors that have been extended to agriculture, the use of permanent and well-equipped experiment stations, where trained workers shall devote their time and energy to the solution of its problems. Thoroughness and continuity are essential, for these problems really deal with all conditions of existence in the water. Of what does the food of each fish consist, where is it found and in what amount, how may it be increased and improved; to what extent and how can the number of fish be multiplied, and how far is this profitable; what are the best kinds of fish and what new varieties can be produced? These are a few of the many questions to be solved.

The problems outlined are indeed vast, and yet we may be confident that their solution lies easily within the power of the human intellect, for they are all paralleled in the history of the agricultural development of the race; and man, relying upon his success in the past, may go forward with supreme confidence to the attainment of their solution in this new field.

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THE THEORY OF ENERGY AND THE LIVING WORLD. THE PHYSIOLOGY OF ALIMENTATION.[1]

By A. Dastre.

I.—GENERAL DISCUSSION OF ENERGY.[2]

A new term, that of energy, was introduced in the natural sciences some years ago, and its significance has continually increased in importance. The English physicists, and especially the English electricians, have had most to do in bringing this new expression into scientific technology. The idea which it conveys is of the highest utility in its industrial applications, and it was from an industrial origin that the term has been expanded and generalized. It is now, however, not merely of practical signification, but a theoretical conception of capital importance in pure science. It has indeed come to the point of being in itself a science—energetics, so called. Although born but yesterday, this new comer claims to embrace and fuse together in itself all the other natural sciences, both physical and pertaining to life, which only the imperfect condition of our knowledge had till now kept separate and distinct.

At the threshold of this new science we must inscribe the principle of the conservation of energy, of which it may well be said that it dominates natural philosophy. The discovery of this principle has marked a new era and accomplished a profound revolution in our conception of the universe. It is due to a physician, Robert Mayer, who practiced his art in a small village of Würtemberg. He formulated the new principle in 1842, and successively developed its consequences in a series of publications which appeared between 1845 and 1851. These remained, however, almost unnoticed and ignored until Helmholtz, in his celebrated memoir upon the conservation of force, placed them

[1] Translated from Revue des Deux Mondes, 1898, Vol. CXLVI, pp. 668–683; Vol. CXLVII, pp. 189–204; and Vol. CL, pp. 201–216.

[2] References: Paul Janet, Premiers principes d'electricité industrielle, Paris, 1893; Ch. Friedel, Préface au Traité de chimie organique de A. Béhal, Paris, 1896; W. Ostwald, Abrégé de chimie générale, Paris, 1893; A. Bouasse, Introduction à l'étude des théories de la mécanique, 1895; A. Reychler, Les Thèmes physico-chimiques, 1897; H. Le Chatelier, Sur l'Energétique, Revue des sciences, 1893.

in such a light as to lend them the importance they deserved. From that moment the name of the modest physician of Heilbronn has taken rank among the most illustrious scientists.

As to the science of energetics, of which thermodynamics is but a single section, it must be admitted that even if it does not already absorb mechanics, astronomy, physics, chemistry, and physiology, and constitute the general and, for the future, unique natural science, still it constitutes a preliminary movement toward that ideal state and a long step in the pathway of progress.

We propose to illustrate these new ideas, first in their general bearing and then with special reference to their application to physiology, or, in other words, their influence on the phenomena of life.

I.

According to most physicists the phenomena of the universe call into play two, and only two, elementary and fundamental things, to wit, matter and energy. All that we see consists in changes in the one or the other of these two forms. This is, one might say, the postulate of experimental science.

To be sure, it is difficult to give a definition to the conception of matter satisfactory to the metaphysicists. It will always be admissible to discuss or even to deny its existence. Even the physicist or physiologist, convinced that man knows nothing except through his own sensations, and that he makes nothing of them except he first objectivize or project them from himself by some sort of hereditary illusion, may hesitate in ascribing an objective character to matter. Another difficulty presents itself even after this one is gotten over and matter comes to be defined as that which has extension or weight or mass. For, as regards weight as the characteristic of matter, physicists recognize a certain imponderable kind of matter, the ether, which has only a sort of logical existence, founded on the necessity of a medium for the propagation of heat, light, and electricity. As regards mass—that is, the mechanical parameter—it is necessary to introduce the term energy, or the allied term, force, in order to define mass, so that we should consequently be defining matter in terms of energy. Thus there appears to be some reason to think the two fundamental elements not irreducible.

It is necessary to avoid these difficulties. The physicist neglects them provisionally; that is to say, he defers their consideration. As a first approximation matter may be considered as that which has weight. Through chemistry we learn that matter has many forms. There are simple substances, classed as metals and metalloids, and compounds, either organic or inorganic. Chemistry may be called the history of the mutations of matter. From the time of Lavoisier its transformations have been followed, balance in hand, and it has been shown that they all take place without change of weight. If we imagine a system of bodies inclosed in a tight receptacle and placed upon the pan of a balance, all the chemical reactions which could take place, though they profoundly modified the form and state of the substances, would not be able to affect the equilibrium of the balance. The total weight remains unchanged. It is this equality of weight which is expressed by all the chemical equations. From a more elevated point of view we see here the verification of one of the greatest laws of nature, the law of Lavoisier, or the law of the conservation of matter, or, still again, the law of the indestructibility of matter: "Nothing is lost; nothing is created; everything is transformed."

The conception of energy is not less clear than that of matter; it is only more novel. Its conception requires us to habituate ourselves to the thought that there are no isolated phenomena. The older natural philosophy had but a limited view of things, and considered them as independent of each other. Phenomena were classed for purposes of analysis into distinct groups, such as weight, heat, electricity, magnetism, and light. Each phenomenon was considered apart without reference to what preceded or followed after it. Nothing could be more artificial than such a method. In reality every manifestation is linked to some other. There is a metamorphosis from one state of things to another—a mutation. A bond of union connects the state which is anterior to that which follows—the new form which appears with the old form which vanishes. The science of energy shows us that something has passed from the one condition to the other, only covering itself with a new investiture; that in the passage from one state to the other there was something both permanent and active, and that the change is but in aspect.

The thing which remains constant under the vicissitudes of form, and which connects in a definite manner the antecedent to the phenomena which follows, is energy. This gives us, however, but a vague and seemingly arbitrary view of energy. It is to be rendered precise only by the study of examples in mechanical, chemical, thermal, and electrical phenomena. Energy takes on corresponding forms throughout these diverse modes.

Mechanical energy is the most simple and the earliest known of these various forms. Mechanical phenomena may be known through two fundamental conditions, space and time, which are of logical origin; and to these is joined a third, which is solely the result of experiment (its origin being in our outward sensation), which is known either as force, as work, or as power.

Our ideas of force, work, and power have their source in the muscular activity of man. In their definition and development they have employed the genius of the greatest mathematicians from Descartes to Leibnitz.

A man supports a burden without stooping or bending. It is a weight—that is, a body or mass under the influence of the force of gravity—which is opposing his efforts, and the man exerts a force sufficient to destroy the effect of the weight. This effect, which is nullified by the effort of the man, would be to cause the body to fall. The man's effort is in equilibrium with the weight and is equal and opposite to it. It gives him the sensation of exerting force, that is to say, the action which is able to produce or prevent motion.

The muscular activity of man may be called out in another way. When workmen are employed, as Carnot has said in his essay upon equilibrium and motion, it is of no consequence "to know what burdens they can reasonably support," but only those which they can carry. "This is the meaning attached to the word force when it is said that the horse has the force of seven men. It is not meant that if the horse pulls one way and seven men the other, their efforts will be in equilibrium, but that in a piece of work the horse, for example, could raise as much weight to a given height in a given time as seven men." Here we are concerned with the second form of muscular activity, which is called in mechanics work, if we do not lay particular stress on the words "in a given time," and think only of employing muscular activity with reference solely to its final result. Mechanical work may be expressed in terms of raising a weight; and it is measured by the product of the force (used in the usual sense, that is, meaning the cause of motion or the hindrance to motion) by the distance through which it causes motion. The unit of work is the kilogram-meter, or the work required to raise a weight of a kilogram to the height of a meter.

Time does not enter into the estimation of work; for this conception is entirely free from considerations of time or velocity. "The greater or less rapidity with which we execute a piece of work can not serve as a measure of its amount, any more than the number of years that a man spends in growing rich or in ruining himself indicates the rise or decline of his fortune."

To revert to the comparison of Carnot, a farmer who employed laborers only by the job, and who would care only for the quality of work irrespective of the time it occupied, would be at the same point of view as those who discuss the theory of mechanics. M. Bouasse, whom we follow here, remarks that this idea of work is due to Descartes. His predecessors, and particularly Galileo, had an entirely different method of measuring mechanical activity, and the same is true of his successors, the mathematicians of the eighteenth century. Leibnitz and still later Jean Bernouilli were almost alone in adopting this view.

It is precisely this idea of work that constitutes the conception of mechanical energy. It represents the durable effect of mechanical activity independent of all the circumstances of its execution. The same work may be done under very different conditions as regards the time, velocity, and force applied in its accomplishment. Energy is therefore the constant element in the midst of the variety of mechanical aspect.

It is that, for instance, which in the collision of bodies remains to effect the rebound. We say that the energy is conserved invariable amid all mechanical transformations.

In the history of mechanics we learn with what difficulty the ideas of force and work (now known as mechanical energy) have been distinguished. Force has no objective existence, no duration, no permanence. It is measured by its effect, the motion which it produces. When, for example, an hydraulic press is put in operation, there is exerted upon the platform exactly the same work which is expended at the piston. The machine only produces a change in the manner of doing work. But, on the other hand, the force is multiplied indefinitely. The whole surface at the platform may be considered as made up of small areas each equal to that of the small piston and, by Pascal's principle, each acted upon by the same pressure applied at the piston. The moment this pressure ceases, the relatively infinite pressure at the platform falls to zero. What real thing can fall instantly from infinity to zero? Work and force belong to different orders of things; they can not have the same expression. Force is a vector quantity; that is, it includes the idea of direction. Work is a scaler quantity, which admits of the opposition of senses involved in the terms plus and minus. Energy, and in this only it differs from work, is a quantity admitting not even opposition of sign. We shall see a little further on, however, that a very eminent physiologist, M. Chauveau, has proposed the same term, "the energy of contraction," for the two phenomena of effort and of work. It might seem from the point of view of the expenditure of the organism that these two modes of activity, the contraction static and the contraction dynamic, are really comparable. But although this way of regarding the matter may be perfectly exact and of value, the author's persistence in using nomenclature contrary to the received usage has prevented the acceptance of very useful facts by physicists and even by some physiologists.

The idea of mechanical power differs from either that of force or of work. It includes the idea of time. In describing a mechanical operation it is not sufficient to give the amount of work done, for the time occupied is an important factor. This is especially the case when the conditions of accomplishment are being considered, as in comparing machines. The one which does the work in the shortest time is called the most powerful. The unit of power is that of a machine which executes 1 kilogram-meter in a second. For industrial purposes a unit 75 times as great as this, called the cheval-vapeur, is frequently employed. It is the power of a machine which does 75 kilogram-meters per second. In electrical industries power is reckoned in kilowatts (equal to 36 cheval-vapeur) or in watts, a unit one-thousandth as great.

It is useless to attempt to determine the power of the human machine relative to industrial machines; for experiment has shown that the mechanical power of living beings depends upon the nature of the work done. Very interesting researches upon this matter were communicated by the celebrated physicist, Coulomb, to the institute in the year 1797. A man of 70 kilograms average weight was occupied with ascending the stairs of a house 20 meters high. He made the ascension at the rate of 14 meters a minute and kept up this rate effectively for four hours. The work thus done was equivalent to 235,000 kilogram-meters. But when instead of mounting without load the man was made to carry a weight, the result was quite different. Coulomb's laborer carried up 6 loads of wood in a day to a height of 12 meters in 66 trips. This would correspond to a maximum work of 109,000 kilogram-meters, instead of 235,000.

Energy, or mechanical work, may be discovered in two forms—actual or kinetic energy, corresponding to a mechanical action being actually performed, and potential energy, or energy in reserve.

A body when raised to a certain height develops in its fall an amount of work in kilogram-meters equal to the product of its weight by the distance through which it falls. This work may be applied in various ways. In this way, for example, public clocks are driven. Now, when the weight is being wound up, when the works are lax, and no motion occurs, the ancient physics would say that there was nothing to consider. The phenomenon is the fall. That will take place, but for the moment there is nothing occurring.

In energetics the reasoning is different. The body is said to possess a capacity for work which it manifests upon a suitable occasion; it has stored-up energy, the power of exerting energy, or potential energy. When the body falls, this potential energy becomes transformed into actual or kinetic energy. The work done by the weight in falling is exactly equal and opposite to that done in winding the clock. This is the source of the energy gradually expended in eight or fifteen days in the regular movement of the hands and the striking of the hours. The fall is the counterpart of the elevation. There is recovered in the second phase of the phenomenon exactly the amount of energy expended in the first. Between the two phases may intervene as long a time as one pleases, during which the energy slumbers, as it were, and of which we speak as a period of potential energy. Thus the connecting link between the phenomena is maintained ever present, and the energy, never lost sight of in these conceptions, is not a new thing when it reappears. Thus we conceive of energy as something real, indestructible, and eternal, having an objective existence; sometimes revealing itself, sometimes slumbering; now manifest, now latent.

Similarly the flow of a torrent of water in a mountainous region may be utilized to drive the water wheels and turbines of the mills in the valley. The fall of the water produces mechanical work which would be a creation ex nihilo if the antecedent phenomena were not taken account of. It can be shown that this is but a case of restitution, for the water was taken from the place to which it now returns, and raised by the action of natural forces. Thus it was evaporated by the heat of the sun, formed into clouds, transferred by the winds, etc. Here, then, is but an example of a complex energy transformation, first from actual to potential energy, and then back again, with neither loss nor gain.

There are as many forms of energy as of distinct varieties of phenomena. Physicists distinguish two species of mechanical energy—the energy of position and energy of motion. There are several varieties of the former species, including distance energy or force, of which we have already spoken; surface energy, corresponding to the phenomena of surface tension, and volume energy, which corresponds to the phenomena of pressure. It would be useless for the purposes we have in view to discuss mechanical energy at great length. It is more important to show briefly that the various known forms of energy may be transformed, the one into the other. These forms are heat, electrical, magnetic, chemical, and radient energies.

It is taught nowadays in all elementary treatises on physics that mechanical work may be transformed into heat and reciprocally heat into mechanical work. Friction, collision and percussion, compression and expansion, destroy or annihilate the mechanical energy communicated to a body or to the parts of a machine. At the same time that the motion disappears heat appears. Examples are abundant. There is the box of the wheel heated by the friction of the spindle; the ignition of particles of steel broken off in breaking the stone; the melting of two pieces of ice by Davy by rubbing them together, although surrounded by objects below the freezing point; the boiling of water by drilling, as observed by Rumford in the boring of bronze cannon in 1790; the ignition of particles of metal in beating upon the anvil; the rise of temperature even to the point of fusion in lead balls fired against a resisting obstacle, and, finally, the origin of fire in the fable of Prometheus by means of rubbing pieces of wood together in the way still called by the Hindoos prâ manthâ. There is a constant correlation between the phenomena of heat and motion, a correlation which has become so well known that observers have ceased to verify it by individual cases. There is no destruction in the true sense of the word. That which is lost in one form reappears under another, giving the impression of something indestructible, which manifests itself in successive disguises. This impression is translated into words in saying that mechanical energy is metamorphosed into thermal energy.

This interpretation takes on a character of startling precision when these mutations are examined with the almost absolute accuracy of physical measurement. It is then shown that the rate of the exchange is invariable. The transformations of heat into motion and vice versa are accomplished in accordance with a vigorous numerical law, which fixes the quantity of energy of the one kind transformed into the other. The mechanical effect is evaluated, as we have said, in work; that is, in kilogram-meters. Heat is measured in calories, the calorie being the amount of heat required to raise the temperature 1 degree of a kilogram of water (large calorie) or 1 gram of water (small calorie). It has been shown that whatever be the phenomena which serve in an intermediary manner to accomplish the transformation, it always requires 425 kilogram-meters to create 1 calorie, or 0.00234 calorie to create 1 kilogram-meter. The number 425 is the mechanical equivalent of the calorie, or, as it is inaccurately said, of heat. This fact constitutes the principle of the equivalence of heat and mechanical work.

Chemical activity has not as yet been measured directly. But it has been shown that chemical activity can engender all the other kinds of energy. It is, indeed, the commonest source of them all, and is principally utilized to obtain heat, electricity, and mechanical energy. In the steam engine, for example, the power is derived from the combustion of carbon by oxygen of the air, which produces the heat required to vaporize the water, develop the force of vapor, and finally to drive the piston. The theory of the steam engine may be reduced to two propositions: Chemical activity engenders heat, heat engenders motion. Or to employ language to which no doubt the reader is accustomed, chemical energy is transformed into heat energy, and the latter into mechanical energy. The transformations are all governed by fixed numerical rules.

Our knowledge of chemical energy is less advanced than that of heat and mechanical motion. There have been as yet no applications to its transformations of processes of measurement suitable for direct numerical verification. It can only be affirmed, not quantitatively demonstrated, that chemical and heat energies are equivalent, for in the present state of science it is impossible to measure chemical energy. The known forms of energy may be expressed as the product of two factors. Thus mechanical energy of motion is measured by the product of the mass by the velocity; heat energy by the product of the temperature and the specific heat; electrical energy by the product of the quantity of electricity by the electro-motive force. As regards chemical energy, it is suspected that it may be directly measured according to the system of Berthollet as revised by the Norwegian chemists, Guldberg and Waage, by the product of the mass by a force or coefficient of affinity, which depends on the nature of the substance taken, the temperature, and other physical conditions of the reaction. In another direction the admirable researches of M. Berthelot have enabled us to make an indirect evaluation in a majority of cases through the heat equivalent of reactions.

It is interesting to note that chemical energy also appears on the face of things to have two states, of potential and real energy. The union of carbon and oxygen in their combustion in the furnace of a steam engine must first be started by a preliminary lighting, just as a weight raised and left stationary at a certain height must be detached from its support by a small expenditure of work. This condition of energy is much in evidence. We shall admit the existence of a latent state, or state of potential chemical energy. In the example just given, the carbon under the preliminary excitation combines with oxygen and forms carbonic acid gas. The potential energy becomes actual energy and immediately is transformed into heat. A very incomplete and fragmentary conception of the matter would be formed if the phenomenon of combustion solely were regarded and it was neglected to inquire after the source of the energy thus dissipated. The antecedent fact is the action of the sun upon growing vegetation. The carbon which burns in the furnace of the engine comes from a mine where it was accumulated. in the state of coal, a primitive vegetable product which was formed indirectly from the carbonic acid of the air. By the aid of the solar energy the plant had separated the carbon from the oxygen to which it was united in the carbonic acid of the atmosphere and had created potential chemical energy, which through the lapse of ages awaited its utilization. Combustion dissipated this energy in re-forming carbonic acid.

The fecundity of the conception of energy is seen from these examples to lie in the connection which it establishes between the phenomena of nature, and that it thus reestablishes a proper articulation, necessarily broken in the ancient analytical view of the sciences. We are led to see in the phenomena of the world nothing but the mutations of energy. In these mutations themselves we see the circulation of an indestructible agent, which passes from one form to another as if it but changed into disguise. If our intellects required images or symbols to embrace the facts and seize upon their import they are at hand. They materialize energy, making of it a sort of imaginary being and conferring upon it a real objectivity. It then becomes for the mind, on condition that the latter does not become the dupe of a phantom itself has raised, an artifice eminently comprehensive, and capable of rendering the greatest assistance in grasping the relation and affiliation of phenomena.

The world then appears, as we said at the beginning, to be constructed with singular symmetry. It offers us nothing but mutations of matter and mutations of energy. These two kinds of metamorphoses are governed by two laws similar and necessary, the conservation of matter and the conservation of energy, which these maintain, the first, that matter is indestructible and passes from one phenomena to another in integrity and equality of weight; the second, that energy is indestructible, and that it passes from one phenomena to the other in rigid equivalence numerically determined by the researches of physicists.

The first problem of energetics is to examine the different forms of energy, to consider them in their relation to each other, to determine if their mutual transformations can be directly realized, and if so to follow this means to determine their quantitative equivalence. This is a laborious task, which extends over the whole field of physics.

Such an examination suffices to show that mechanical energy may be transformed into all the other forms and all the other forms into it, with one exception, that of chemical energy. Our knowledge of the rôle of pressure in dissociation reactions seems at first to abolish this restriction. But this appearance is deceptive. The pressure does not enter into this operation except as a preliminary condition or incentive, merely putting the bodies in such a state relative to each other that chemical affinity can come into play.

In connection with the calorific and luminous forms of radiant energy it should be noted that they are not as distinct as was believed by the older physicists. To consider the matter objectively, there is no light without heat. It is the same agent which at a certain interval in its scale differently impresses the skin and the retina of men and animals. The difference in sensation is to be imputed to the diversity of the organ, not to the diversity of the agent. At lesser degrees of activity this agent exercises no effect either on the terminations of the thermal nerves of the skin or on the retina. As its degree of activity augments (infra-red heating) the thermal nerves are first impressed, and quite to the exclusion of the nerves of vision. Next both are impressed (sensation of light), and finally the sight only is affected. The transformation of energy therefore reduces itself in this case to the possibility of intensifying or diminishing the action of the common agent to such conditions as suit the passage from one state to another, and this may easily be brought about.

It may be remarked that this form of energy of which we have been speaking can not be transformed directly into chemical energy. To be sure, radiant energy favors and determines many chemical reactions, but if we go down into the root of the thing we must admit that the radiation serves only to incite the phenomena, to prepare for the chemical reaction, to put the bodies into such a state (liquid, perhaps, or vapor) or temperature (400 for instance in the combination of oxygen and hydrogen) as suits the entrance upon the scene of chemical affinity. On the contrary, chemical energy may be transformed into heat and radiant energy, as could be illustrated by numerous examples in which no other forms of energy are present, and by others where, as in the combustion of hydrogen and carbon, or in explosive decompositions, reactions continue of themselves when once initiated.

Other restrictions appear in studying the laws which govern the transformations and transference of heat energy, the most important of which maintains the impossibility of heat transfer from a body at a lower to a body at a higher temperature. As the result of all these restrictions heat is an imperfect form of the universal energy, or, as it is expressed by the English, a degraded form.

On the other hand, electrical energy represents a perfect and highly advantageous form of this universal energy, and this explains the immense development which has taken place in its industrial application within less than a century. Not that it is better known than the others in its essence and in the last analysis of its actions; quite the contrary! Its nature is still discussed. Some, in consideration of its immense velocity of transmission and its similarity to light, have considered it to be a veritable flow of the ether, like Father Secchi, who assimilated it with the flow of water in a conduit. According to this view, electrical work is comparable with that done by water pressure in the hydraulic motor. Thus, eléctricity itself would not be a form of energy, but only a vehicle for energy. However, most physicists follow the view of Clausius and more recently of Hertz, who held that it is not energy itself which is thus propagated, but a vibratory motion. Be that as it may, the most characteristic property of electrical energy and that which renders it of the greatest value is its extraordinary capacity for transformation. All other known forms of energy may be converted into electrical energy and conversely with the greatest facility. This extreme docility assigns to electricity the rôle of intermediary in the transformation of the other less tractable agents. Mechanical energy, for example, is not readily transformed into radiant energy. A fall of water can not be directly utilized for lighting purposes, but in the installation of industrial lighting plants; the water power is first caused to drive a dynamo, which then feeds the incandescent or arc lights. Otherwise unavailable mechanical work is constantly being turned into electrical energy, and the latter into heat and light. Electricity has taken up the post of an intermediary agent.

And now if we wish to develop the programme of the science of energy it is necessary to indicate the second great principle, that which according to Robert Mayer controls all its transformations, the principle of Carnot. Next it should be shown by some numerical example, some concrete illustration, how contemporary science has taken account of the nature and the transformations of energy. Following this the kinetic theory should be expounded. The universe of matter according to this theory is conceived as animated by two kinds of motions, the visible and the molecular. An historical treatment should be followed of the manner in which this hypothesis was introduced in physical science owing to the necessity of taking account of the phenomena of the propagation of light; how it was formed in the study of heat; how made precise, thanks to Clausius and Maxwell, in the case of gases, and how, finally, it has been extended to the manifestations of electricity and magnetism. We can not undertake this task here for two reasons. The first is that the kinetic theory, which has scarcely yet, through infinite pains, arrived at its full elaboration, already shows signs of decadence and ruin. Physical theorists of one school already express doubt of the existence of the ether, the medium necessary for the propagation of the radiant energy, and they deny that electricity is a mode of motion or even that heat and light are such. They deign to erect nothing upon the ruins of this theory, which has become so firmly rooted upon the contemporary mind that it is in some sort a part of the ambient mentality. To a generation reared in admiration and respect of the efforts of genius which have compassed the creation of this system, they propose contempt for all its images, the symbols or the material representations of scientific truth. They offer us, to explain the natural phenomena, systems of three or six differential equations, which to them contain no hypotheses. Whether the future will sustain or condemn them we are not competent to prophesy. But the main reason which deters us from the task, doubtless beyond our powers of tracing the kinetic hypothesis, is that it is not essential for our purpose. We merely propose to show in what follows how the consideration of energy and of its first fundamental principle, that of its conservation, have transformed the point of view of physiology on three great questions, the conception of the vital phenomena in their relation to the general phenomena of nature, the theory of alimentation, and finally the origin of muscular force.

II.—THE ENERGY OF LIFE.[1]

I.

Despite the efforts of a small number of experimenters from Harvey to Magendie, the science of life has been outstripped in the progress of the other natural sciences. It remained a long time embalmed in scholastics and incumbered by such systems as animism and vitalism, according to which vital phenomena were governed by a principle distinct from the physical forces, and thus their difference from other natural phenomena was accentuated.

These systems were dominant in the schools of the time of Lavoisier, and still acted as a check on the experimental method in the time of Claude Bernard. They have scarcely disappeared entirely even in our day. In 1878 an eminent physician, who occupied one of the highest positions of instruction, E. Chauffard, attempted to restore the animism of Stahl. Still more recently we have seen discoveries of two foreign scientists of legitimate reputation, Heidenhain, of Breslau, and Ch. Bohr of Copenhagen, serving to resuscitate the name "neo-vitalism," a doctrine much preached by those who in the last century supported Bordeu and Barthez. The contemporaneous neo-vitalism borrowed from its forerunner its fundamental principle, the unique character, not only in form but in essence, of vitality, and its absolute irreducibility to anything physical. To be sure this was coupled in the ancient vitalism with another notion which the progress of ideas did not permit to be revived in our time. It considered physiological phenomena to be the immediate effect of a special cause, an agent of some sort personified,

[1] References: A. Chauveau; La Vie et l'Énergie chez l'animal, 1894. La Valeur énergétique des alimens (Académie des sciences), 1897. F. Laulanié: Énergétique musculaire, 1898. J. Loeb: La Physiologie générale, son but et son histoire (Pfluger's Archiv), 1898. A. Gautier: Leçons de chimie biologique, 1897.

the vital principle exterior to the living being, independent of its substance, bonded to it temporarily, working, it might be said, with human hands, and accomplishing the deeds and actions of life, and at last quitting the body which had served as its hostelry, not perhaps under the form of a butterfly, the graceful genius of the Greeks, but in a manner equally real if less visible. The vitalists of the middle ages, like Paracelsus and Van Helmont, had divided up this principle of life into subordinate principles, and multiplied these personifications under the name of arches. Some trace of them may be discovered in the vital properties of Bichat and others of the moderns, phantoms which Cl. Bernard loved to compare to the nymphs, dryads, and sylvans of mythology.

In the face of physicians and philosophers who explained the phenomena of life as the liberated activity of a vital principle, distinct or not from the thinking soul, arose an adverse system, the mechanical. The scientific spirit has evinced in all epochs a lively predilection for this doctrine, and in our day it has finished by adopting it and confounding the other. A single order of things now embraces life and the physical phenomena, for all the phenomena of the universe reduce to an identical mechanism, and are represented by the atoms and their motion. This conception of the world which the philosophers of the Ionic school had originated in remote antiquity, and which Descartes and Leibnitz later had modified, has come down to us under the name of the kinetic theory. The mechanism of atoms, ponderable or imponderable, contains the explanation of all phenomena. Physical properties and the manifestations of life, the whole world even, offers nothing in the last analysis but motion. All phenomena are expressed by an atomic integral, and in this we find the majestic unity which dominates modern physics. The forces of life can not be distinguished in their ultimate examination from other natural forces; all are confounded in molecular mechanics.

Without arguing the philosophical value of this doctrine, which indeed has justified its sway over physical sciences by the discoveries to which it has given rise, it may be observed that it has been of small aid in biology. It is precisely because it descends too profoundly to the root of the thing and that it is analytic to the last degree that it ceases to explain. The step is too far from the hypothetical atom to the apparent and concrete facts for the former to assist in accounting for the latter. The tangible vital phenomena lose their proper appearance, and can no longer be recognized in their traits, either specific or universal.

On the other hand, the theory of energy conduces to a conception quite as general, but at the same time more sure, more comprehensive, and sufficiently near the reality to be translated into facts, and continually to acquire new vigor. Its introduction in biology dates but from yesterday as it were, but it has already taken a considerable place and rendered valuable service. It has inspired researches replete with interest, and has renovated the appearance of certain branches of physiology.

It begins to have a place in the courses of higher instruction in the universities of Germany, America, and France. M. Chauveau is the foremost exponent of these new tendencies among us; his works and those of his students form the most important contribution (of our time) to the constitution of physiological energetics.

II.

The doctrine of energy was first conceived in physiology before it was taken up in the department of physics with such extraordinary acceptation. Robert Mayer was a naturalist and a physician. Helmholtz was a physiologist before he became a physicist. Both saw in the new idea a powerful instrument for physiological investigation. The publication in which Mayer set forth in 1845 his remarkable views on the movements of organisms in their relation to nutrition and the commentary of Helmholtz dispel all doubt in respect to their positions in this regard. The "Remarks upon the mechanical equivalent of heat" were published about six years after this first work.

The doctrine of energy is in our day but returning to the science which was its cradle. It returns, sanctioned by the demonstrations of physics, as the most general doctrine which has ever been proposed in natural philosophy, and is the one least weighted by hypotheses. It reduces to two fundamental principles the multitude of minor principles and the smaller number previously recognized as general which had dominated the sciences of nature. It can be shown without great difficulty that the principle of Robert Mayer, suitably extended, contains the principle of the inertia of matter stated by Galileo and Descartes; that of the quality of action and reaction ascribed to Newton; even that of the conservation of matter (or rather of mass) due to Lavoisier, and finally the experimental law of equivalence which is associated with the name of the distinguished English physicist Joule and from which is derived the principle of Hess, and the principle of "initial and final states" of Berthelot.

Similarly Carnot's principle, as extended in a large and comprehensive fashion by contemporary theorists, such as William Thomson (Lord Kelvin), Le Chatelier, and others, may be considered as the universal law of mechanical, physical, and chemical equilibrium. It includes, as G. Robin has shown, d'Alembert's principle of virtual velocities, and, according to some physicists, the special laws of chemical and physico-chemical equilibrium.

These two principles, then, contain the essence of all natural sciences. Since the true significance of these laws is to express the necessary relations of all the phenomena of the universe, they impart a real homogeneity to apparent diversity, and hence they may be made to follow from the "idea of continuity" of nature as opposed to "physical discontinuity." The unity in the world, the diversity in the spirit, is the fundamental doctrine of E. Kant. Thus the natural philosophy of our time is personified in the names of Kant, R. Mayer, and Carnot. It would be derogatory to doctrines so universal and so thoroughly verified in the physical world should they be confined here and remain without value in the science of life. Such a supposition would be contrary to that spirit of generalization which is essentially the scientific spirit, and which consists in a belief in the existence, the constancy, and the extension of elementary laws.

Scientists have always proceeded in one way under such circumstances. They have applied the most general laws of contemporary physics to the phenomena of life, a procedure which has been found legitimate and productive of results abundantly verified by experimental data when applied to really fundamental laws, but most unfortunate and attended with a still more gross materialism when falsely carried on. For Descartes, the body was a machine functionally supplied according to the laws of natural philosophy; but he carried this view too far in descending to particulars, and considering the body solely as a combination of springs, levers, presses, sieves, pipes, retorts, and alembics. Liebnitz, on the other hand, was clearly within reasonable bounds when he said "The body develops itself mechanically, and the laws of mechanics are never violated in the natural movements." Claude Bernard was also reasonable in applying the general principles of Galileo on the inertia of matter to living beings when he affirmed that the apparent spontaneity of vital actions was only an appearance and illusion; that the vital phenomena were always adequately caused; that they were the response to an exterior stimulation and the result of conflict between living matter and the physical and chemical agents which are incentive to the action, but which are always foreign to it, even though contained within the boundaries of the organism.

Thus in applying to life the general laws of energetics we follow in the path of science and conform to the traditional method. It can not be doubted that such application is legitimate and that experiment will justify the application a posteriori. Such, indeed, has been the outcome.

The living, like the inanimate world, offers us then nothing but mutations of matter and energy. The varied manifestations of activity in the living being, corresponding to transformations of the species and varieties of energy, conform to the rules of equivalence determined by physicists. In the physical world the specific forms of energy are less numerous. When we have enumerated mechanical, chemical, radiant, thermal, luminous, and electrical energy (the latter with its attendant magnetic energy) we have exhausted the list of actors which occupy the scene in the material world, at least so far as we know.

Can we, then, say that the lists are closed and that science will never discover other forms and specific varieties of energy? Not at all. Such an affirmation would be at once as ambitious as imprudent. The history of the physical sciences ought to render us more circumspect. It teaches us that little more than a century has passed since electrical energy has made its entrance upon the scene, and we have commenced to know this form of energy. Such a discovery as this, right under our eyes, of an agent playing such an important part in nature should leave the door open in the future for other surprises.

This reservation is of great importance from the point of view of the arrangement of the phenomena of life in the universal science of energetics. It allows us to admit that in addition to those forms of energy which are common in the physical world, other varieties may be met with in the living organism such as are peculiar to it. These are still too little known to be sought out elsewhere; but doubtless they exist also in the physical world, and will come to light when our means of investigation shall have become sufficiently advanced. At present we must admit their possibility to account for the peculiarity of some of the phenomena of life which are quite special and different from those of physics. With this precaution we recognize at once wherein the vital phenomena reduce themselves to the domain of universal physics, and wherein a provisional separation still remains. We thus escape the charge of gross materialism incurred by Descartes and Boerhave, those uncompromising scientists who thought to discover in the actual instruments of our laboratories the model of all mechanisms, even the most complex, of animal life; a proposition as vain as it would have been for an iatro-mechanician to have tried to explain before the time of Lavoisier the elementary phenomena of respiration or the phenomena of the excitation of the nerves before Volta.

But on the other hand we must recognize the profound truth lying behind this extreme and unfortunate realism, which, acting through an obscure and common instinct, has constrained the biologists of all times to attempt to bring the phenomena of life under the empire of general physics.

We now know with certainty that many forms of energy are common to the living and physical worlds, and these energies—chemical, thermal, and mechanical—retain their character of mutability, their scale of equivalence, and their states of being, actual and potential.

If it shall happen again, as it happened in the last century in regard to electricity, that some unrecognized form of energy is suggested by physiological researches, we can affirm in all confidence that this new energy will obey no new laws. It will be governed in its transformation into the known forms by the rules already determined; it will appertain to the universal order as well as to life, and it will be a conquest for general physics as well as for biology. It can easily be understood after these explanations of the significance and portent of that affirmation, which is the foundation of biological energetics, that the phenomena of life are energetic metamorphoses in the same sense as the phenomena of nature.

The science which has been christened the "energetics of biology" is not new. It is none other than the general physiology to which no one in any country has contributed more for its foundation and enrichment than Claude Bernard. It must be recognized, however, that R. Mayer and Helmholtz have more distinctively characterized and limited the field in defining it as "the study of the phenomena of life from the standpoint of energy."

A school of experimental zoologists, arisen within the last few years in Germany, has attempted to monopolize and distort general physiology by designating it simply as the study of cellular life. They have affected to believe that physiology from the time of Galen down has had no interest except in the working of the organs, and they oppose to this "physiology of organs" their "physiology of cells." A qualified scientist, J. Loeb, scarcely does justice to these pretensions. He shows that "cellular structure" is in most cases a matter as completely of indifference as the "structure of organs" in the action of vital forces; and that it is necessary to banish this morphological notion of the physics of living matter as being nothing more to general physiology than the physics of inanimate bodies. The determination of the vital energy of plants and animals, the direct transformation of chemical energy of nutrition into animal heat or into muscular energy, the chemical evolution of the aliment, and the study of the soluble ferments—these are the things which in his view are likely to increase our knowledge of the mechanism of life. It is these things which are most advanced by the study of biological energetics.

III.

The equivalence or identity of the energies developed in the animal with the universal forms of energy in nature has furnished the point of departure for this doctrine. Two other principles go with this to lay the foundation, to wit: That vital energy has its origin in some form of external energy, and not in all the forms as might be supposed —but in one of them exclusively, chemical energy. This energy is finally converted and issues forth in a few other well-determined forms.

This is the importation, more precisely expressed in terms of energy, of an idea similar to the vital vortex of Cuvier and the naturalists in the order of matter. This idea of Cuvier defines life by its most constant property, nutrition; that is, by the existence of a current of matter which the organism gathers from without by alimentation, rejects by excretion; a current the complete interruption of which even for a moment would be the signal of death. The circulation of energy is the exact counterpart of this conception of the circulation of matter.

The second principle drawn from experience and made use of by general physiology may be thus enunciated: The maintenance of life consumes no energy peculiar to and originating with the living being. It borrows from the external world in the form of chemical potential all that it requires. Such is a translation into the language of energetics of results acquired in animal physiology within the last fifty years. It is unnecessary for the commentator to emphasize the importance of such a principle; for it reveals the origin of animal activity—the source from which proceeds the energy which at one point in its transformation becomes the vital energy.

The primum movens of vital activity is then, according to these principles, the chemical energy stored up in the material composing the organism.

To attempt to follow out the movement it is necessary to be precise. Let us suppose our attention concentrated upon a limited portion of the organism—a certain tissue. We will come upon it in the uninterrupted course of its life at the given moment, and from this time on examine its functions. The first effect we notice will be the liberation of a portion of the potential energy lying concealed in the materials put in reserve in the tissues. This disengaged material furnishes the energy required for the continuance of the vital function of the tissues. There is, then, at the beginning of its functional process, and as a necessary part of this process, a liberation of chemical energy which can not be brought about except by a decomposition of the immediate constituents of the tissues or, following a customary expression, by the destruction of organic material. Claude Bernard has stringently insisted upon this consideration that vital activity is accompanied by a destruction of organic material. "When a movement takes place or a muscle contracts, when the will or the emotions are excited, or the brain exercised, or when the glands secrete, the substance of the muscles, the nerves, the brain, or the granular tissue is decomposed, destroyed, and consumed." The real reason of this coincidence between chemical decomposition and functional activity, of which Claude Bernard had an intuition, has been made clear to us by energetics. A portion of the organic material being decomposed descends in the scale of chemical complexity, and in so doing gives up its chemical potential energy. In this store of energy lies the means for vital activity.

It is obvious that the store of reserve energy thus drawn upon must be replenished if the organism is to preserve its equilibrium. Alimentation provides for this by furnishing the materials. The action of the digestive apparatus prepares them for assimilation; that is, it reduces them to a convenient form to be incorporated in the reserve. This replenishing of the reserves is not a chemical synthesis; it is, as Claude Bernard has termed it, "synthesis of the organism." "The synthesis of the organism," he says "remains hidden silent within, assembling noiselessly the materials which it dispenses."

This great physiologist divided the phenomena of animal life into two categories. The first contains the destruction of reserves which accompanies functional activity; that is, increased expenditure of energy. The second contains the plastic phenomena of the replenishing of the reserves; in other words, organic reorganization, which corresponds to functional repose, and is associated with decreased expenditure and rehabilitation of energy.

If these are not the exact terms employed by Cl. Bernard in formulating his fertile conception, they are those in which his followers have interpreted his thoughts. They have added nothing except precision to his idea. Applying more rigorously than the eminent physiologist, the distinction which he had created between really active living protoplasms and the reserves which these prepare, they recognize that it was necessary to attribute solely to these latter the functions which Bernard deemed to distribute between them.

All that Cl. Bernard held is rigorously true of the reserves. It is easy in these days to criticise the inexactness of expression in which he stated his ideas. The old adage: Obscuritate rerum verba obscurantur, may be his apology. In the darkness of night he had the light of genius. Doubtless he did not find the most definite and polished expression of his thought, but there is no reason for a grammatical quarrel.

If then, there is incontestably a destruction of reserves when vital activity takes place, what happens to the active living matter? Is it the same with it, or does it follow a different course? We do not know. Le Dantec affirms that the living matter is increased rather than destroyed. He gives to this assertion the title of the "Law of functional assimilation," and draws very important conclusions from it. But in reality there is not one of the arguments which he draws to its support which is conclusive. The objections are no more decisive. It is alike vain to attempt in the present state of science either to establish or disprove this proposition by experiment or argument. The cause of this indeterminateness lies in the great number of unknown quantities which enter into the solution of the problem. It is sufficient to enumerate them: the two substances existing in the anatomic element to which we ascribe opposite characteristics; the two conditions which are attributed to them of latent and actual activity; the faculty of either of these to exist for an indefinite time and to encroach upon its protagonist when the other has ceased to be. Here are enough unknown elements to vitiate all the results positive or negative which may be obtained. The proposition, then, can not be demonstrated, but may be accepted without too close examination, like the pills of which Hobbs speaks, which must be taken without chewing.

Energetics leaves this question undecided but inclines nevertheless to the affirmative. The functional assimilation of the protoplasm is not, like the organization of the reserves, a phenomenon approximately without influence on the balance of energy. There is here the constitution of a substance, the active protoplasm, which attains a higher degree of complexity, and whose formation consequently requires an appreciable quantity of energy. Assimilation, in order to be realized, requires the absorption of energy. Now at this same moment the destruction or simplification of the reserve, in consequence of activity, liberates energy which might be applied to this very purpose. If the protoplasm does in reality make use of it its role would be the counterpart of that of the reserves. But if it is uncertain whether the active protoplasm behaves according to the view of Le Dantec, it is certain that the reserves follow the law of Claude Bernard, and the essential part in the energetic changes belongs to them.

IV.

The third principle of the energetics of biology is similarly the result of experiment. It relates not only to the point of departure in the cycle of animal energy but to its terms.

It is here that the greatest novelty of the doctrine lies, and here we may say that it is less understood by physiologists themselves. Energy derived from the chemical potential of the aliment, after having traversed the organisms (or simply the organ which is considered to be in action), and having given rise to more or less diversified phenomena comprising the manifestations proper to, or in some cases still irreducible to, vitality, finally returns to the physical world. This return is made (with some well-known exceptions) under the ultimate form of thermal energy.

The truly vital phenomena are therefore to be classed between the chemical energy which gives birth to them, and the thermal phenomena which they engender in their turn. The place of vital activity in the cycle of universal energy is thus perfectly determined. This is a conclusion of the first importance for biology. We can express this deduction in concise language as follows: Vital energy is ultimately the transformation of chemical energy into heat.

This assertion requires the condition that the animal contents himself with merely living without performing external work.

The founders of animal energetics, and especially M. Chauveau, have attempted to give more precision to this very vague conception, vital energy. The same is true of it as of the ordinary physical forms of energy. We know how to measure it without knowing what it is.

Vital energy is that which accompanies the phenomena of the tissues, and not actually identifiable with the known types of physical, chemical, and mechanical energies. These actions are usually silent and invisible of themselves, and only to be recognized by their effects after the transformation into the familiar forms of energy. Vital energy is that which acts, for instance, in the muscle prepared for contraction, in the nerve which conducts the nervous impulse, and in the glands during secretion. What we call here provisionally the vital property, the energy peculiar to vitality, or the living energy, M. Chauveau calls physiological work. This we here consider as exchangeable from the point of view of equivalence with the energies of physics, just as these are among themselves. This is the significance of the first law of energetics.

Energetics teaches us that if chemical energy is the generating form productive of vital energy, heat energy is the form of ejection, or emunctory form, which is spoken of as degraded by physicists. Heat is, in the dynamical order, of the same category as urea, carbonic acid and water, the excreta in the material order. It is, therefore, entirely through a false interpretation of the principle of the mechanical equivalence of heat, or in ignorance of Carnot's principle, that some physiologists still speak of the transformation of heat into motion, or into electricity, in the animal organism. Heat transforms itself into nothing in the animal organism; it is only dissipated. Its utility comes, not from its energetic value, but from its function in promoting chemical reactions, as has already been explained in speaking of the general characteristics of chemical energy.

The consequences of these clear and general principles of physiological energetics are of the greatest importance from a practical as well as from a theoretical point of view.

First, they show clearly the rank of the phenomena of life in the universe. They are necessary to the understanding of that beautiful harmony between the animal and vegetable kingdoms which Priestly, Ingenhousz, Senebier and the chemical school of the beginning of the century had disclosed, and which Dumas has described with such incomparable clearness and success. Energetics expresses the thing thus: The animal world employs the energy which the vegetable world accumulates. Energetics goes beyond the bounds of life and to the midst of cosmos. It shows how the vegetable world itself draws its activity from the radiant energy of the sun, and how the animal life at last restores the heat thus dissipated. The harmony between these two kingdoms extends throughout nature. It makes a closed system of the whole universe.

From a more restricted point of view, and considering only the domain of animal physiology, the laws of energetics embrace the function and general principles of alimentation. The aliment is essentially a source of energy, and only in an accessory way a source of heat. Precisely the contrary is usually taught in our medical colleges; and this error, though perhaps of no importance from the point of view of practice, is, on the other hand, highly important as a matter of doctrine. The energy which the aliment brings to the animal is the potential chemical energy which it possesses by virtue of its chemical complexity. It is this requirement of substances far up in the scale of chemical complexity which links the animal to the vegetable, the latter being alone capable of producing these syntheses. The animal activity liberates a part of the potential energy which the plant has formed. Chemistry enables us to compute the quantity of energy which an aliment thus disengages. It applies Berthelot's principle of the initial and final state; and by utilizing the numerical tables established by this eminent chemist with such admirable patience, we obtain in calories the quantity of energy which the aliment furnishes to the organism. Thus we know its dynamogenic or thermal power.

This energy, whose exact amount is now known for each category of aliments, is made use of in accordance with the third principle. It is to be transformed following two possible types. In the normal type it is transformed first into vital energy (the physiological work of Chauveau) and subsequently either into mechanical work (the movement of the muscles) or into thermal energy (heat which is dissipated externally). In this normal case the aliment has wholly accomplished its office, since it has served to sustain the vital functions. It has been dynamogenic, or bio-thermogenic.

On the other hand, we have the possibility of the abnormal or aberrant type. It may happen that, in virtue of its chemical nature, and for reasons just beginning to be understood, the aliment in its decomposition liberates energy which the organism is unable to make use of, and which in consequence is not transformed into vital energy or any kind of physiological activity, but passes directly into the thermal state. A category of such aliments might be mentioned, or rather a list of substances of this nature, for they scarcely merit the name aliment. Alcohol and the acids which exist in fruits, such as malic, and citric acids fall in this type. They may be called pure thermogens. Some physiologists—and their error has its origin in the common habit of prejudgment—still imagine that alcohol is a generator of force, dangerous, to be sure, on account of its abuse, but still a source of energy as much as sugar or fat, and thus capable of furnishing part of the energy necessary to the execution of difficult tasks. This is erroneous. To be sure, alcohol decomposes or is consumed in the organism, and produces heat, but that only serves to be uselessly dissipated. The heat produced within the body is no more efficacious than that which comes from the heat of the climate or of our fires. The pure thermogens are then exclusively employed in producing internal heating. Aliments such as we have discussed under the name of bio-thermogens are equally as much as these a source of internal heating, but also participate in the vital functions.

In saying that the cycle of energy which runs its course in the animal organism takes its departure in the chemical disintegration of the aliment, physiologists employ a formula too general and not sufficiently approximate to the truth. Hence there have arisen confusion, misunderstandings, and controversies, which revive continually and give to this branch of physiology an appearance of being in an unsettled and disordered condition, which ought not to exist. It is not the vital activity in its generality which should be considered when one wishes to treat of the facts and applications, but a single functional act in particular. It is then seen that the source of energy which this act puts in play is found in the substance of the organ and in the active tissue, and not in the aliment in the condition in which the animal imports it from without. In other words, it is not the aliment in the rough which is the source of energy, but the aliment digested, modified, elaborated, and incorporated as an integral part of the tissue which employs it; in short, in the state of reserve. All the principles of physiological energetics of which we have spoken apply to the aliment as refined, and in this state only; that is, as a part of the reserves. Are they also applicable to the aliment in the strict sense of the word? Only in another fashion. Between the substance of the aliment and the substance of the reserves there are differences resulting from the various processes which have been employed from the time when the aliment was originally introduced into the organism to that when it becomes assimilated in its proper place. These preparations may be very numerous, and they are in most cases still unknown. It is generally admitted, however, that they are such as to use up so little energy that its quantity may safely be neglected. The supposition is warranted in certain cases, but, on the other hand, it is erroneous in a greater number. M. Chauveau has very clearly exposed this error of the theorists on alimentation. He has been able to determine the amount of energy so used in certain processes, by means of very ingenious experiments.

But this is not the place to discuss this matter. Nor shall we examine the new and very interesting controversy on physiological dietetics. We must restrict ourselves to incidentally indicating the most general relations of the theory of alimentation with the subjects of our present inquiry, which is to illustrate the fundamental principles of the energetics of living beings.

III.—THE PHYSIOLOGY OF ALIMENTATION.

What is an aliment, and in what does alimentation consist? This is a question which no one takes the trouble to answer—at least if he be a physician, a physiologist, or a zoologist. A Frenchman who knows his language will reply, like the dictionary, that "the term aliment is applied to all those substances, of whatever nature, that habitually serve or are able to serve the purposes of nutrition." The thing is easy to understand; it is anything used by a decent man to nourish himself. If you want to know more, ask the cook.

That would be one solution; but there are many others. The problem of alimentation presents a thousand aspects. It is culinary and gastronomic of course, but it is also economic and social, agricultural, financial, hygienic, medical, and even moral. And first of all, and before all, it is physiological. It is from this point of view that we shall discuss it here—solely and entirely that aspect which concerns the phenomena of life.

It is needful to know the general composition of the aliment, and to distinguish between substances which merit the name and those which usurp it, in order to understand its function. We must follow its various transformations, and fix the quantity of the ration of repose as compared with that of the person when working actively. We must determine the effects of inanition, of insufficient nourishment, and of superabundant nourishment. In a word, we must examine the most intimate and delicate reactions by which the organism exhausts itself and repairs its wastes; and, to repeat the expression of a celebrated physiologist we must inspect "the kitchen of vital phenomena." Neither Apicius, nor Brillat Savarin, nor Berchoux, nor the moralists, nor the economists can serve as our guides. It will be necessary to consult those scientists who, following the example of Lavoisier, Berzelius, Regnault, and Liebig, have applied the resources of general science to the study of life and thus have founded the chemistry of biology.

This branch of physiology has made very considerable progress within the last half century, and now maintains separately its methods, its technique, its chairs in universities, its laboratories, and its collections. Its special application is to the study of the "material changes" or metabolism of living beings. Two branches of this subject have been studied: First, the composition of the materials going to make up the organism has been determined, and second, qualitative and quantitative analyses have been made of all the substances entering or leaving it. This includes all that is absorbed through respiratory and food channels on the one hand, and all excreta through the various channels on the other. Thus the nutritive balance sheet has been made out corresponding to various conditions of life both naturally and artificially reared. It can be said which items go to sustain and benefit, which to exhaust and reduce, and which finally strike the balance.

We do not propose to give a detailed account of this scientific movement, for that is a field for special treatises. We intend merely to indicate here the most important results of these laborious researches, including the general laws which have been built up and the theories which have been sustained. This is as far as the subject belongs to general science, and is of interest to the nonspecial reader. Matters of detail have no lack of historians; it is far more profitable to show the trend of ideas. The theories of alimentation present many conceptions of the operation of vital functions. There is so great a number of conflicting opinions on this subject that it is not without interest to attempt to clear it up.

I.

Cl. Bernard remarked, in respect to life, that it is impossible to give it a scientific definition. And this is true not only of life, but of nutrition and in particular of the aliment. All the physiologists and physicians who have attempted to define an aliment have failed. Most of the definitions, both common and learned, have interposed the condition that the substance should be introduced through the digestive apparatus. These definitions summarily exclude from the class of beings sustained by alimentation all vegetables and animals not provided with an intestinal canal; and they leave out various substances which enter the body through other channels than the stomach, which, like the oxygen for example, participate to a large degree in the sustaining of life.

The distinctive feature of the aliment is the use that it may be, when rightly employed, to the living creature. It is a substance necessary to the maintenance of the phenomena of living organisms, and the reparation of losses to which they are subjected, says Cl. Bernard—a substance which carries an element essential to the constitution of the organism or which diminishes its disintegration (conserving aliment), according to the German physiologist Voit—a substance which contributes to assure the good operation of any of the organs of a living being, following the much too broad definition of Duclaux. All these characterizations, however, give but an imperfect idea of it.

The introduction of the idea of energy into physiology has given a better understanding of the true nature of the aliment. It is necessary to recur to the doctrine of energetics to take into account all that the organism requires it to furnish. The organism demands not only matter but energy. The naturalists consider only the necessity of contributing matter, and thus look upon the problem from only one point of view. The living body presents in each of these directions an uninterrupted succession of tearing down and rebuilding, the materials for which are furnished by alimentation and rejected by excretion. Cuvier called this incessant passage of surrounding matter into and through the vital world the "vital vortex," and regarded it with reason as the characteristic of nutrition, and the distinctive trait of life.

This idea of the circulation of matter has been completed in our own time by that of the circulation of energy. All the phenomena of the universe, and more especially those of life, are conceived as changes of energy. They are now regarded in connection with their environment rather than in isolation as formerly. Each has an antecedent and a consequent whose magnitude is determined by a numerical law of equivalence established by the contemporary physics. Thus the succession of events is conceived as the circulation of a sort of indestructible agent, which changes only in appearance or disguise in passing on, but which suffers no loss; and this is energy.

The most general result of the study of physiological chemistry has been to teach us that the antecedent of the vital phenomenon is always chemical.[1] Vital energy originates in the potential chemical energy

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[1] See the discussion of the subject on previous pages of this paper.

accumulated in the material of which the organism is composed. The phenomenon consequent to the expenditure of vital energy is usually the production of heat. Vital energy is transformed into thermal energy. These three propositions relating to the nature, origin, and termination of the vital phenomena are the three fundamental principles, the three laws, of the energetics of biology.

The place of vital energy in the universal classification of energy is, from what has been said, perfectly determined. It belongs between chemical energy, from which it springs, and thermal energy, into which it is resolved, and which is the "degraded form" of energy, to use the expression of physicists. From this follows a deduction of immediate application in the theory of the aliment. Heat is an excretum of the dynamic order from the living being, quite as much as urea, carbonic acid, and water are excreta of the material order. It is therefore quite incorrect to speak of the transformation of heat into vital energy in the animal organism, although this expression is in common use. Nor is it more proper to speak of the transformation of heat into muscular motion, as was held by Béclard, or into animal electricity, as has been maintained by other writers. These are errors of doctrine as well as of fact. They imply a false interpretation of the principle of the mechanical equivalence of heat, and the misunderstanding of Carnot's principle. Thermal energy does not ascend the energetic scale in the process of vital phenomena. Heat never transforms itself; it is simply dissipated.

Is this the same as saying that heat is not essential to life? Far from it, for it is most necessary. But the function of heat is a peculiar one which should neither be misunderstood nor exaggerated. It is not transformed by chemical or vital reactions, but merely helps to create the proper conditions for such reactions.

According to the first principles of energetics, in order that vital energy should be derived from thermal energy it is necessary for the latter first to be converted into chemical energy, since that is the form antecedent to and productive of vital energy. Now this retrograde transformation is impossible according to the received doctrines of general physics. The rôle of heat in the act of chemical combination is merely to aid the reaction, to put the reacting substances in such condition as regards temperature that the chemical forces are at liberty to exert themselves. For example, in the union of oxygen and hydrogen by igniting an explosive mixture of these gases, the heat merely promotes the phenomenon. The two gases are indifferent to each other at ordinary temperatures, and require to be raised to a temperature of about 400° in order to put in play the chemical affinity between them. It is in a similar way that reactions are promoted in an organism. They have a most favorable temperature which it is the rôle of animal heat to furnish.

Thus we have shown that heat enters into the conditions of animal life in two ways; First as an excretum the product of animal activity, and second as a factor to promote chemical reactions. Its dissipation then is not a pure loss. The author drew these conclusions some years since from certain experiments on the alimentary value of alcohol, not knowing that they had already been expressed by a contemporary physiologist (A. Chauveau), and that they were already associated in his mind with other conceptions of great interest, in the development of which the author has since had the good fortune to assist.

II.

To say that an aliment is a bearer of energy as well as matter is to express in brief the fundamental idea of biology, by virtue of which life is no longer thought of as creating any power special to itself. A living being is looked upon as the scene of an incessant circulation of matter and energy which comes from the exterior world and again returns to it. Matter and energy together wholly constitute the aliment. All its characteristics, the appreciation of its function, of its evolution, and of the laws of alimentation, follow as the consequences of this principle interpreted in the light of energetics.

We first inquire what forms of energy are carried by the aliment. It may be readily seen that there are at least two. For it is essentially the source of chemical energy and secondarily and in an accessory manner a source of heat. Chemical energy alone, as we see from the second law of energetics, is suitable for transportation into vital energy. This is true at least for animals, but for plants it is otherwise. Their vital cycle has neither the same point of departure nor destination, nor does the transformation of energy here follow the same course.

Again—and this is the third great law governing the phenomena—the energy put in play in life is restored to the physical world in the form of heat. We have remarked that the disengaged heat is employed first to raise the internal temperature of the living being. This is the animal warmth.

There are therefore two kinds of energy furnished by the aliment; but if it is wished to be very exact and to omit nothing it should be added that they are not the only two but only the two principal and by far the most important forms. It is not absolutely true that heat is the only energy product of the vital cycle. This is the case only for the animal in repose, when it contents itself with mere placid existence without engaging in external mechanical work, such as raising external weights, or even that of its own body. Mechanical work is then a second possible termination of the vital energy cycle, but is not necessarily so, for the motion and employment of force by animals are subordinated to their volition. Again, the vital energy cycle may terminate in the production of electricity, and such indeed is the case with the operations of the nerves and muscles of all animals, and with the operation of the special electric organ in certain fishes, such as the ray and torpedo. Finally luminous energy may be produced from vital energy, as is the case with the phosphorescent animals.

It is useless to weaken principles by thus enumerating all the restrictions which attend them. It is well known that there are no absolute natural principles. It is sufficient to say that the energy which temporarily animates living creatures is furnished to them from the external world exclusively in the form of potential chemical energy, and that it returns to the outer world chiefly in the form of heat but partially in the accessory form of mechanical energy.

It is clear that if the flow of energy which circulates through the animal leaves it solely in the form of heat, then this heat becomes a possible measure of the amount of energy originally furnished by the aliment. If the outward flow is divided between two channels, heat and mechanical work, the two amounts of energy thus given up must be added together. In the case where the product is heat alone we need only to determine the loss of heat by the calorimeter to have a measure of the consumption of energy in living. Physiologists have arranged apparatus in various forms for this determination. Lavoisier and Laplace employed the ice calorimeter. They placed an animal of small size in an ice cage and determined the amount of heat given out by the amount of ice melted. In one of their experiments they found that the Indian pig melted 341 grams of ice in ten hours and consequently furnished 27 calories of heat.

More recently a better instrument has been devised. M. d'Arsonval employed an air calorimeter, which is nothing but a differential thermometer very ingeniously constructed and made self-registering. Rosenthal, Richet, Hirn and Kaufmann, and Lafèvre have used air calorimeters more or less complex. Others, following the example of Dulong and of Despretz, have used water and mercury calorimeters, or like Liebermeister, Winternitz, and Lefèvre have had recourse to the method of baths. There have been many of these researches and they have contributed very interesting results.

The same problem may be solved in another way. Instead of determining the energy leaving the body in the form of heat it may be measured before its entrance in the form of chemical potential. This determination has been made in the same units as the preceding—that is to say, in calories. It has been owing to the advances in thermo-chemistry and to the principles advanced in 1864 by Berthelot that this second method of arriving at the energetic equivalent of nutrition has become possible. Physiologists by the aid of these methods have established the balance of energy for the living being in various conditions, as they had already done before for matter. If it is asked what has been the outcome of these researches, we reply that it consists in having determined an enormous mass of separate facts, of which we can not here speak, but which have served to build up the general doctrine of the energetics of biology—that fertile conception which enables us to deduce the explanation of the most intricate and disputed phenomena of nutrition as the consequence of three simple laws.

Examples abound of the fecundity and innate power of these ideas. To illustrate by a single point, take the long-cherished error of physiologists who believed with Béclard, in the transformation within the organism of heat into mechanical work. After the establishment of the doctrine of energy this error was no longer possible. Energetics teaches us that the current of energy divides itself in leaving the body into two divergent branches, one thermal and the other mechanical, which are strangers to each other though springing from a common source, and have no other relation in common except, that in summation, they represent the total energy of life.

We will now clothe these simple ideas in words more or less foreign to the usage of physiology; and in so doing, we are convinced, to use the words of Buffon, that "the language of science is more difficult to comprehend than science itself." The amount of chemical energy which a unit weight of a given aliment is able to furnish to an organism, and which may be evaluated according to the principles of thermo-chemistry by the aid of the numerical tables of Berthelot, Rubner, and Stohmann, constitutes the alimentary potential, or energetic value of the substance, or in still other words, its dynamogenic power. The same number expresses also the thermogenic power, actual or theoretical, of the alimentary substance. This energy being destined to be transformed into vital energy (termed physiological work by Chauveau, or physiological energy) the dynamogenic and thermogenic value of the aliment is at the same time its biogenetic value. Two weights of different aliments for which these numerical values are the same are said to be isodynamogenic, isobiogenetic, or isoenergetic weights. They are equivalent from the point of view of their alimentary value. Finally if, as is usually the case, the cycle of energy is finished by the production of heat, the aliment which has been used for this purpose has a real thermogenic value identical with its theoretical thermogenic value as may be experimentally determined by direct calorimetry.

III.

The aliment is a source of thermal energy for the organism by which it is decomposed. Physiological chemistry teaches us that whatever be the method of its decomposition, it always finally reaches the same condition, and with the evolution of the same quantity of heat. But if the point of departure and the point of destination are the same, the route followed is not necessarily identical. For example, 1 gram of fat always furnishes the same quantity of heat, 9.4 calories, and is always rejected in the same condition of carbonic acid and water. But from the state of fat to that of a mixture of carbonic acid and water there are many intermediate conditions. Various alimentary cycles are therefore possible.

From the point of view of their production of heat, these cycles are all equivalent. But are they equivalent from the vital point of view?

Consider an ordinary alternative. The aliment passes from the initial to the final state after being incorpotated with the elements of the tissues and having participated in the vital operations. Here the limentary potential is transferred into thermal energy after having traversed the intermediate phase of vital energy. This is a normal case, the regular type in the alimentary evolution. In this case it might be said that the aliment had fully performed its function; it had served vital purposes before being changed in the heat, and had been biothermogenic. Now consider the most simple case of the irregular or aberrant type. The aliment passes from the initial to the final state without being incorporated in the living cellules of the organism, and without taking part in its vital functions. It remains confined in the blood and circulating fluids, but finally undergoes the same molecular disintegration and liberates the same quantity of heat. Its chemical energy changes at the first attack into thermal energy. The aliment is a pure thermogene. It has abdicated a portion of its functions and has been of less vital utility.

Does this case present itself in reality? Can the same aliment be, as supposed, a biothermogene and a pure thermogene? Some physiologists, among them Fick of Wurtzburg, have maintained that it was actually so with most aliments; the nitrogenous substances, hydrocarbons and fats, all being capable of either of these transformations. On the other hand Zuntz and von Mering have absolutely denied the existence of the aberrant type of pure thermogene, maintaining that no substances whatever are directly decomposed into organic liquids without the functional intervention of the histological elements. Still other authors, finally, teach that a small number of alimentary substances thus suffer direct decomposition, and among them alcohol.

The "theory of luxurious expenditure," of J. Liebig, and the "theory of circulating albumen," of Voit, affirm that the proteid aliments suffer in part a direct combustion in the blood vessels. This subject has occasioned a celebrated discussion, and the opinions of physiologists are still divided upon it. Disengaging the main object of discussion from all the side issues which have been raised, the question is whether an aliment always follows the same course of evolution whatever be the circumstances, and in particular if it be introduced in great excess. Liebig held that the superabundant portion escaping by ordinary processes was destroyed by direct combustion. He affirmed, for instance, that substances containing an excessive amount of nitrogen instead of running the usual cycle of vital operations suffered direct combustion in the blood. We express the same idea to-day when we say that they sustain an accelerated evolution, and that their energy, omitting the intermediate stage, passes at once from the chemical to the thermal form. The doctrine of Liebig, reduced to this fundamental idea, merits survival. Accessory errors compressed its ruin.

Some years later the celebrated chemist and physiologist of Munich, C. Voit, revived this doctrine in a more pronounced form. According to him nearly the whole albuminoid aliment was consumed directly in the blood. He interpreted certain experiments upon the utilization of nitrogenous aliments by supposing that these substances when introduced into the blood by digestive processes were divided into two portions. One very small portion incorporated itself in the living organism and passed to the state of "organic albumen." The remainder was mixed with the blood and lymph, and suffered direct combustion, this being the circulating albumen. In this doctrine the tissues were regarded as nearly stable, only the organic liquids being subject to nutritive metabolism. The accelerated evolution regarded as exceptional in the doctrine of energetics, was looked upon as the rule by C. Voit. Pflüger and the Bonn school have corrected this abusive exaggeration.

The fact, long known, that the consumption of oxygen is notably augmented (to as much as five times its usual value) after eating, is favorable to the supposition that some nutritive substances are absorbed and pass into the blood, to be immediately oxidized and destroyed at once. To be sure some experiments of Zuntz and von Mering are contrary to this view, for they injected oxidizable substances into the blood vessels without discovering immediate oxidation. But on the other hand, more favorable results of such experiments have been known.

If the accelerated evolution of the ordinary aliment is thus uncertain it seems that there is undoubtedly a special category of pure thermogens, such as alcohol and the acids of fruit. When alcohol is taken in moderate doses about a tenth of the quantity absorbed is taken up by the living elements. The remainder is "the alcohol of circulation" which is directly oxidized in the blood and the lymph, without intervening in the vital operations other than by the heat which it produces. According to the theory of energetics such substances are not true aliments, since their potential energy is not transformed into vital energy, but passes at once to the form of heat. On the other hand some physiologists regard alcohol as a true aliment. In their view everything is an aliment which is transformed in the system into heat, and they measure the nutritive value of a substance by the number of calories it produces. By this measure alcohol would be a superior aliment to the carbohydrates and nitrogenous substances. A given quantity of alcohol, a gram for example, is equal from this thermal point of view to 1.66 grams of sugar, to 1.44 grams of albumen, and to 0.73 gram of fat. These quantities would be isodynamic.

This is evidently an extreme view, for experience condemns it. The researches of C. von Noorden have directly shown that alcohol can not be substituted in a ration in the place of an isodynamic quantity of carbohydrates. If this substitution be made, a ration before just capable of maintaining an organism in equilibrium becomes insufficient; the body loses weight; the nitrogenous materials which enter into its constitution are broken up, and the animal declines.

In the preceding we have accustomed ourselves to look upon a single characteristic of an aliment (though its first essential, to be sure) as its energetic character. It is necessary that it furnish energy to the organism, and in order to do so it must be decomposed or broken up into simpler substances. Thus fat, which has rather a complicated molecular structure from a chemical point of view, is given off as carbonic acid and water. The same is true for the carbohydrates, such as saccharine and amylaceous substances. It is because of the simplification in structure attending the passage of these substances through the organism that they give up the chemical energy which they have stored up in the potential form. Thermo-chemistry enables us to determine from the initial and final states the amount of energy given over to the living being in the interim. This energetic value, dynamogenic or thermogenic, gives thus a measure of the alimentary capacity of the substance. A gram of fat, for example, gives up a quantity of energy equal to 9.4 calories; the thermogenic value of the carbohydrates is about half as great, or 4.2 calories; and the thermogenic value of albuminoids is 4.8 calories. This being so we see that the animal is best nourished by aliments which are of very complicated chemical structure.

IV.

In addition to the energetic theory which we have always discussed there is another way of conceiving the role of the aliment. It consists in the consideration of the aliment as a source of heat. We have seen that an aliment is a source of thermal energy for the organism. Inversely, can it be said that all substances which give out heat when brought into the organism are aliments? This is a much controverted question at present. Most physiologists admit that it is so. Their notion of an aliment is interchangeable with that which produces heat; in their idea everything is nutritive which disengages heat within the body. The most imperative need of the living body is to be kept warm. Even cold-blooded animals have a constant internal temperature which must be maintained for the preservation of their lives. On the other hand the animal heat of the body is continually dissipated in the colder surrounding medium. Hence a continuous supply of thermal energy is necessary for the preservation of life. Hence the necessity for alimentation is mixed up in the necessity of a vehicle for heat to cover the deficit due to the inevitable cooling off of the organism. As a rule the amount of heat thus lost governs the need and fixes the quantity of the ration.

Such is the theory which opposes the energetic theory and disputes favor with it among physiologists. Among its strongest adherents are von Noorden, Rubner, Ch. Richet, and Lapicque. In their view the generation of heat absolutely dominates the play of nutritive exchanges; and it is the heat requirement which regulates the total demand in calories for the support of the organism. It is not at all because the organism produces too much heat that it disperses it over all its surface, but emphatically because that it would lose heat to a dangerous extent that it is adapted to provide against the loss.

This conception of the function of alimentation rests on two arguments. The first is furnished by the experiments of Rubner. A dog is kept a suitably long time (from two to twelve days) in a calorimeter, and the quantity of heat given off is compared with the heat furnished in the food. The accord between the two is in every case remarkable. But would it be possible that it could be otherwise? For in a mechanical regulator it is well known that an exact equilibrium between the supply of heat and the loss must obtain for a constant temperature within. The second argument is drawn from what is called the law of surfaces, brought forth by Ch. Richet. By comparing the proper rations of subjects of very different weights placed in various situations, it was shown that there was furnished always the same number of calories for the same surface of skin—that is to say, the same cooling surface. This is certainly a very interesting fact, but at the same time not necessarily convincing.

There are, on the other hand, grave objections to this view. The thermal value of a nutritive principle represents only one aspect of its physiological function. To be sure man and animals are able to draw the same profit and the same effects from rations in which one of the aliments is replaced in isodynamic proportions by two others, and the same quantity of heat is thus developed. But this substitution is very limited in its possibilities. Isodynamic substitution—that is, a substitution of aliments pro rata for their thermal value, is limited on all sides by exceptions. In the first place, there is a small quantity of nitrogenous aliment whose place can not be supplied. Indeed, even before the minimum allowance is reached the substitution seems to be perfect. While substitution is perfect as between the albuminoids and carbohydrates and the fats, it can not safely be made between these and the nitrogenous substances. If the heating power of aliments was the only consideration, an isodynamic substitution would not shut out alcohol, glycerin, and the fatty acids from completely supporting alimentation. Finally, if the thermal power of an aliment is the sole measure of its physiological utility, the question arises why aliments could not be wholly replaced by a dose of heat. Heating from without might, it seems, take the place of heating from within. One could cherish the ambition of substituting for rations of sugar and fat an isodynamic quantity of carbon, used to nourish the man at the same time that it suitably warmed his apartment.

V.

In reality the aliment has another office to perform than to warm the body or even furnish it with energy. It should not be forgotten that the organism requires a supply of matter as well as a supply of energy. It must have a proper quantity of certain definite principles, both organic and mineral. These principles are evidently for the purpose of replacing the substances carried out in the circulation of matter, and to reconstruct the organic material. Such aliments may be called histogenetic (repairers of tissues) or plastic aliments.

This was the view of alimentation taken by the ancients. Hippocrates, Aristotle, and Galen believed in the existence of a special nutritive substance existing in all the infinite variety of substances employed for nourishment by men and animals. It was not until the time of Lavoisier that the idea of the dynamogenic and thermal value of the aliment was conceived. The combined view of these two species of attributes and their accurate distinction is due to J. Liebig, who designated them as plastic and dynamogenic aliments. He held also that the same substance might serve in both these rôles, and this he thought to be the case with the albuminoids.

The elder Magendie, in 1836, had introduced, in an interminable list of aliments, a preliminary division into proteid substances (now called albuminoids, nitrogenous and quarternary substances) and terniary substances.

The proteids are capable of alone sustaining life. Preponderating importance should be attributed to this class of aliments. These results of Magendie have been since verified. Pflüger, of Bonn, has given a convincing demonstration of them within a year. He nourished, worked, and finally fattened a dog upon meat alone. The same experiment showed that the organism can form fat and carbohydrates at the expense of nitrogenous aliments, and can transform the one class of substances into the other. Fats and carbohydrates are therefore not essential, the albuminoids alone being indispensable. Theoretically man and animals may sustain life exclusive of proteid aliments, but practically this is not possible for man because of the enormous quantity of meat (3 kilos per day) which he ought properly to use.

Ordinary alimentation employs a mixture of these three kinds of substances, and in this mixture the albumen contains the plastic element actually necessary to repair the waste of the organism. The two other kinds carry the required energy. In such mixed diets the quantity of albumen ought never to fall below a certain minimum. The efforts of physiologists in the last few years have tended to fix with precision this minimum ration of albuminoids, or, as it may be said in abbreviated fashion, to determine the quantity of albumen below which the organism perishes. Voit has indicated as the limit for man 118 grams of meat. This figure, however, is certainly too high, and may be reduced to 100, to 90, or even to 70. But, on the other hand, the most advantageous ration of albumen should be considerably above that actually sufficient.

It remains to mention several recent researches. The most important of these by far are those which M. Chauveau has published upon the reciprocal transformations of immediate principles in the organism, according to its functional conditions and the circumstances of its activity. We shall find a natural opportunity to speak of this at suitable length in treating of the physiology of the muscular contraction and movement; in other words, the subject of muscular energetics.

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THE ECONOMIC STATUS OF INSECTS AS A CLASS.[1]

By L. O. Howard.

The popular conception of insects in general is undoubtedly that they are injurious. Many writers, it is true, have pointed out the benefits derived from insects, but we think of their damage to crops and of their annoyance to man and animals, and this aspect of the subject is at once apt to preponderate in our minds. It is more than eighty years since Kirby and Spence contrasted the injuries caused by insects with the benefits derived from them, and it has not been comprehensively done since. In the meantime, whole groups of important injuries have been developed and whole classes of beneficial work have been discovered. Moreover, the tendency of modern thought has not taken this direction. The biologic, taxonomic and phylogenetic, and other aspects of large groups of forms of life have been considered to the exclusion of the economic aspect, and even where this side has attracted attention investigators have confined themselves to specific problems and have not generalized. It may be interesting, therefore, once more to contrast the injurious insects with the beneficial ones in an effort to gain a clearer idea of the status of the group in its relations with man.

In a broad way, we may consider the subject under the following heads:

Insects are injurious:

1. As destroyers of crops and other valuable plant life.
2. As destroyers of stored foods, dwellings, clothes, books, etc.
3. As injuring live stock and other useful animals.
4. As annoying man.
5. As carriers of disease.

Insects are beneficial:

1. As destroyers of injurious insects.
2. As destroyers of noxious plants.
3. As pollenizers of plants.
4. As scavengers.
5. As makers of soil.
6. As food (both for man and for poultry, song birds, and food fishes) and as clothing, and as used in the arts.

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[1] Address of the retiring president of the Biological Society of Washington, delivered January 18, 1899. Printed in Science, Vol. IX, No. 216, February 17, 1899.

DESTROYERS OF CROPS AND OTHER USEFUL PLANTS.

In the present balance of nature one of the chief functions of insect life is to keep down superabundant vegetation. Almost every kind of plant has its insect enemies, and has had such enemies for many thousands of years. So soon as man began to make an effort to upset nature's balance by cultivating certain plants at the expense of others he encountered nature's opposition by means of the increase of insect enemies of the particular plant cultivated, and almost as early as there is any record of agriculture in literature there is also mention of the destruction to crops caused by insects. Witness the writings of the prophet Joel, who might almost be termed an agricultural pessimist.

At the present time almost every cultivated crop has not only its thousands upon thousands of individual insect enemies, but it is affected by scores and even hundreds of species. A mere tabulation of the insect enemies of the apple already recognized in this country shows 281 species, of clover 82 species, and of so new a crop as the sugar beet 70 species. The insects of the vine, of the orange, of the wheat crop, and, in fact, of all of our prominent staples, show equally startling figures.

The actual damage which is done by insects in this way is difficult to express. Many attempts have been made by writers on economic entomology to express it in money values. For example, it was estimated by the late Professor Riley that the average annual damage to cultivated crops by injurious insects in the United States amounted to $300,000,000. The loss from the ravages of one species alone, the chinch bug, during one year was estimated at $60,000,000. While it is true that the combined losses of individual growers might reach such enormous sums as these, there is an element in the total loss which we must not fail to take into consideration, and that is the enchanced value of the portion of the crop which remains. Even in the case of an individual a man may lose, for example, half of his crop through the work of the chinch bug, and yet, through widespread damage by this insect, the money value of the portion harvested may reach an amount almost as great as would have been gained through the low prices of a successful year of no insect damage. As this applies to an individual, it applies much more strongly to a State or to the country at large, so that even in the year when the grain crop of the country was said to have been damaged to the extent of $60,000,000 it is safe to say that the total price gained for the crop was as great as it would otherwise have been. These estimates of damage, therefore, would much better be expressed in terms of bushels, or some other measure, than in money value.

It is this aspect of our subject, the damage done by injurious insects to agriculture, that has given rise to the comparatively new branch of applied science which we now know as economic entomology, and which, although originating in Europe, has been encouraged to such an extent in our own country, owing partly to our greater necessities and partly to our practical turn of mind, that it is safe to say that at present America leads the rest of the world in this direction.

It is undoubtedly true that this enormous injury to crops is the chief item in a general consideration of the injuries brought about by insects.

AS DESTROYERS OF FOODS, DWELLINGS, CLOTHES, BOOKS, ETC.

It is safe to say that there is hardly any product of man's ingenuity, hardly one of the thousands of useful materials upon which depend his comfort and happiness, which is not damaged, directly or indirectly, by insects. The timbers of which his dwellings are built, nearly all of his household utensils, his garments, practically everything which he uses as food, many of the liquids used as drink, his books, the ornaments with which he surrounds himself, the medicines which he takes when sick, the very tobacco with which he solaces himself—all are destroyed or injuriously affected by insects. There is, perhaps, one group of exceptions, and that is those articles which are composed wholly of metal, and yet even here insects may occasionally play an injurious part, since instances are on record of the destruction of lead pipes by insect larvæ, and the perforation of the metal linings of water tanks by small beetles.

Such injuries to human products are more frequent and serious in tropical regions than in temperate zones, but even here insects of this nature cause very serious inconvenience and great annual loss. It will answer our purpose, perhaps, to list some of the varying substances which are damaged in this way, to get an idea of their almost universal character: Ham, cheese, salted fish, butter, lard, dried mushrooms, rye bread, sweetmeats and preserves, powdered coffee, almonds and other nuts, raisins, breakfast foods, chocolate, ginger, rhubarb, black pepper, vinegar, sugar, wines, canned soups, tobacco, snuff, licorice, peppermint, aromatic cardamon, aniseed, aconite, belladonna, musk, opium, ginseng, camomile, boneset, hides, shoes, gloves and other leather articles, furniture, carpets, drawings and paintings, paint brushes, gun wads, combs, etc., made of horn; hay, oats, straw, willow baskets, ax handles, ladders, wheel spokes and all sorts of agricultural implements with wooden handles, barrels, wine casks, corks of wine bottles, sheets of cork, natural history collections, including skeletons and mummies, and even Persian insect powder! The mention of this well-known insecticide reminds one of the latest discovery, which is that certain flies in California breed in the crude petroleum pools in the vicinity of oil wells, a fact which is almost paradoxical in view of the extensive use of petroleum as an insecticide.

AS INJURIOUS TO LIVE STOCK AND OTHER USEFUL ANIMALS.

Every species of animal which has become domesticated and is of value to man possesses its insect parasites and enemies. These in many cases are the same species which affect man and which we will mention in the next section; others are specific to the animals or groups of animals which they affect. Horses, cattle, sheep, all possess insect enemies which are not only very deleterious to their health, but frequently cause their death in numbers.

The disgusting bot fly of the horse, whose maggots live in incredible numbers in the stomach and intestines of this noble friend of the human race; the bot fly of the ox, which causes innumerable sores on the backs of cattle and by its perforations ruins their hides for commercial use; the bot fly of the sheep, which inhabits the nasal and orbital sinuses of the sheep and produces insanity and death, will instantly be recalled by those who are familiar with stock raising, while hundreds of other species, some in no less degree, as the horn fly, the numerous gadflies, including the tsetse fly of Africa, the screw-worm fly of our Southwestern country, unite to make the lives of domestic animals a burden to themselves and a trial and a loss to their owners.

An interesting attempt was made some years ago by a prominent Western agricultural newspaper, The Farmers' Review, to estimate approximately the pecuniary loss from the attacks of a single one of these insects—the ox bot fly, or ox warble—on the cattle received at the Union Stock Yards of Chicago. It was estimated that 50 per cent of the cattle received each year are affected. The number of cattle received at the yards during 6 months of the year 1889 was 1,335,026; the average value of the hide was $3.90; the usual deduction for hides damaged by the ox warble was one-third. Estimating at less than one-third, say $1, the actual loss during six months on hides alone was $667,513. When to this was added the loss for depreciation in value and lessened quantity of beef, the loss for each infested animal was put at $5, a very low estimate, indicating the total loss from the animals in the Union Stock Yards of Chicago for a period of six months of $3,336,565.

AS ANNOYING MAN.

There are very few regions of the habitable globe where man is not personally subject to more or less annoyance by insects. In this part of the world we naturally think at once of mosquitoes, house flies, fleas, and of a certain other species which it will not be necessary to name.

A susceptible individual some years ago wrote to the Department of Agriculture and said that he had come over from the old country and settled in New Jersey, but that the mosquitoes bothered him so greatly that on the advice of friends he moved to northern New York. Here he found that during a certain portion of the year black flies made life unendurable; thereupon he packed his household effects and moved to North Carolina. Here, however, in the summer months red bugs, or jiggers, bothered him to such an extent that he feared he would go crazy, and in this desperate condition he applied to this office to learn whether there existed in the United States a locality where a sensitive individual could find peace from attacks of insects. He said that he had been told that in the Western country the buffalo gnat was greatly to be feared, while certain other biting flies would be sure to keep him in a constant state of dermal irritation; that farther south he knew that peaceful nights were to be gained in the summer time only under the protection of mosquito bars. He had thought of the newly developing country of Alaska, but had recently seen an account in the newspaper of the ferocity of the Alaskan mosquitoes, which had practically destroyed his last hope.

Accustomed as most of us are to the mosquitoes of temperate North America, we hardly realize the impression which they made upon the early English travelers. A story told by Kirby and Spence, to the effect that Mr. Weld in his travels relates from General Washington that in one place the mosquitoes were so powerful as to pierce through his boots, has always excited my interest and curiosity, and I recently took the trouble to consult the original publication, which is "Isaac Weld's Travels through North America, 1795–1797," London, 1799. In speaking of Skenesborough, in northern New York, Mr. Weld dilates upon the number and ferocity of the mosquitoes, and makes use of the following words: "General Washington told me that he never was so much annoyed by mosquitoes in any part of America as in Skenesborough, for that they used to bite through the thickest boot." Now, knowing that the boots of those days were very thick and that the mosquitoes of that time must have been structurally identical with those of to-day, there arises instantly a question of veracity between Mr. Weld and General Washington; and as we know from Dr. Weems's veracious history that General Washington was so constituted that he could not tell a lie, it looks very much as though Mr. Weld, like many another English traveler who has written a book on his return home, has been inclined to overstate the truth.

In these days of comparative personal cleanliness some of the most disgusting of the insect annoyers of man have dropped out of sight. The lice, which in former days were common in all classes of society, from king to peasant, are now comparatively unknown. The itch disease, which carried off many a famous character in history, is equally rare. That it still persists, however, is shown by an occasional case reported in medical journals. For example, Dr. Robert Hessler, of Indianapolis, reported in 1892 a case in his own practice of typical Norway itch in which the itch mites were present in the skin of the patient in enormous numbers. A rough estimate showed 7,000,000 eggs and 2,000,000 mites.

Those of us who live in a reasonably civilized way are confined, in our experience of annoying insects, largely to the forms mentioned in our opening paragraph, namely, mosquitoes and house flies and rarely fleas; but a glance through the medical literature reveals the existence of more or less frequent cases of such a nature that they are little less than horrible. Prominent among these are the cases of so-called Myasis, and especially those resulting from the attacks of the screw worm fly, *Compsomyia macellaria.*

Residents of temperate regions are fortunate as compared with those of tropical regions in respect to the personally annoying insects. Our troubles from these individually insignificant causes are intensified to a degree in warmer countries, where the comfort of the individual absolutely depends upon the adoption of measures, always difficult and frequently impracticable, to exclude insects from his person and from his food. This is so well known in these days of numerous books of travel that I will close this aspect of our question simply with a quotation from a poet of the Indies, written many years ago:

> "On every dish the booming beetle falls,
> The cockroach plays, or caterpillar crawls;
> A thousand shapes of variegated hues
> Parade the table and inspect the stews.
> To living walls the swarming hundreds stick,
> Or court, a dainty meal, the oily wick;
> Heaps over heaps their slimy bodies drench.
> Out go the lamps with suffocating stench.
> When hideous insects every plate defile.
> The laugh how empty, and how forced the smile!"

AS CARRIERS OF DISEASE.

Manson's demonstrated transmission of the filaria diseases of the East (elephantiasis, chyluria, and lymph scrotum) by insects; the discovery by Salmon and Smith of the carriage of the germ of Texas fever by the well-known Southern cattle tick; the discovery by Bruce of the fact that the Tsetse fly of Africa is so destructive to animals, not by its bite alone, but by carrying into the circulation of the animal that it attacks the micro-organisms of disease; the demonstration by Howe and others of the previously suspected fact that the purulent conjunctivitis of the Egyptians is spread by the house fly; the partly proven hypothesis of Manson and Grassi of the relation existing between mosquitoes and malaria; the circumstantially proven carriage of the germs of Asiatic cholera and typhoid fever by flies; the demonstration claimed by Finlay of the carriage of a mild type of yellow fever by mosquitoes; the suggestion by Hubbard that the "pink eye" of the South is spread by Hippelates; the well-recognized fact among the Europeans of the Fiji Islands that without a veil a serious native eye disease will spread through the medium of gnats. The suggestion by Symond of the agency of fleas in the spread of the bubonic plague; the demonstration of anthrax bacilli in malignant pustules in human beings, caused by the bite of Tabanus and Stomoxys—all indicate an important and very injurious function of insects practically unsuspected until comparatively recent years. It is, in fact, a rapidly increasing field of investigations, the possibilities of which can not be accurately established at the present time. It is, however, not a field which should be left entirely to the medical bacteriologist; the entomologist should have a share. The life histories and habits of the insects concerned in the damage should be thoroughly understood, since it is not impossible that otherwise the medical investigators may find themselves arriving at perhaps unwarranted conclusions. For example, it is a fact probably unknown to the medical men who may be strongly impressed by the suggested carriage of typhoid germs by flies, that the house fly so common in our dining rooms, rarely breeds in and seldom visits human excrement, while those other kinds of flies, which do so breed, are rarely attracted to articles of food used by human beings. In the crowded and unnatural conditions of army camps, however, and especially where cavalry regiments are stationed so that there are great amounts of horse manure, the house fly may breed in such enormous numbers as to render of very likely occurrence a departure from the normal food habits of the adult.

Enough has been shown, however, to emphasize the potentiality of this phase of insect injury.

BENEFITS.

AS DESTROYERS OF INJURIOUS INSECTS.

The economic bearings of insect enemies of insects are very great, and perhaps this is, all things considered, the most important of the beneficial function of insects as a class.

In the eternal warfare of organism upon organism, in the perpetual strife of species, one preying upon another and that upon a third, the complications of relations of forms which determine the abundance of one species and the scarcity of another are nowhere more marked than among the insects. In fact, to the student of insects who has followed out even a single chain of these interrelationships the thought must necessarily come that upon its organic environment, and especially upon its relations with its living neighbors of the animal kingdom, depend the chances of a species not only for increase, but for survival almost to no lesser degree than upon its inorganic environment. Temperature is the great factor which controls the geographical distribution of life, and temperature is at the back of all these apparent living first causes which control the abundance of a species in a given region, provided we trace them far enough. Yet these living causes, themselves affected by other living causes in an almost endless chain, sometimes, to all appearance, dwarf even temperature as a controlling factor.

There is not a species of insect that has not its natural enemies in the guise of other insects; there is not one of these other insects which has not its own insect foes. From a single species of Bombycid moth, the larvæ of which frequently damage forests in Europe to an alarming extent, there have been reared no less than 60 species of hymenopterous parasites. From a single caterpillar of *Plusia brassicæ* have been reared 2,528 individuals of a little hymenopterous parasite, *Copidosoma truncatellum*.[1]

Outbreaks of injurious insects are frequently stopped as though by magic by the work of insect enemies of the species. Hubbard found, in 1880, that a minute parasite, *Trichogramma pretiosa*, alone and unaided, almost annihilated the fifth brood of the cotton worm in Florida, fully 90 per cent of the eggs of this prolific crop enemy being infested by the parasite. Not longer ago than 1895, in the city of Washington, more than 97 per cent of the caterpillars of one of our most important shade-tree pests were destroyed by parasitic insects, to the complete relief of the city the following year. The Hessian fly, that destructive enemy to wheat crops in the United States, is practically unconsidered by the wheat growers of certain States, for the reason that whenever its numbers begin to be injuriously great its parasites increase to such a degree as to prevent appreciable damage.

The control of a plant-feeding insect by its insect enemies is an extremely complicated matter, since, as we have already hinted, the parasites of the parasites play an important part. The undue multiplication of a vegetable feeder is followed by the undue multiplication of parasites, and their increase is followed by the increase of hyperparasites. Following the very instance of the multiplication of the shade-tree caterpillar just mentioned, the writer was able to determine this parasitic chain during the next season down to quaternary parasitism. Beyond this point true internal parasitism probably did not exist, but even these quaternary parasites were subject to bacterial or fungus disease and to the attacks of predatory insects.

The prime cause of the abundance or scarcity of a leaf-feeding species is, therefore, obscure, since it is hindered by an abundance of primary parasites, favored by an abundance of secondary parasites (since these will destroy the primary parasites), hindered again by an abundance of tertiary parasites, and favored again by an abundance of quaternary parasites.

The subject of practical handling of insect enemies of insects has come into great prominence during the past ten years. The sugges-

[1]This observation, which for some years "held the record," as the expression is, was made by Mr. Pergande, of the United States Department of Agriculture. Recently, however, Prof. A. Giard, of Paris, has more than 3,000 specimens of the same parasite reared from a Plusia caterpillar.

tion by the Rev. Dr. Bethune, of Canada, many years ago, of the desirability of importing the European parasite of the wheat midge into America was probably the first published international suggestion of this nature, and, although some subsequent correspondence between English and American entomologists ensued, no parasites were actually sent over. Later, attempts were made by LeBaron in the case of a parasite of the oyster-shell bark louse of the apple, and by Professor Riley in the case of a parasite of the plum curculio, to transport parasites from one section of the United States to another, both attempts meeting with some slight success.

In 1873 Planchon and Riley introduced an American predatory mite, which feeds in this country on the grape vine *Phylloxera*, into France, where it became established, but where it accomplished no appreciable results in the way of checking the spread of this famous vine pest.

In 1874 efforts were made to send certain parasites of plant lice from England to New Zealand, without recorded results of value.

In 1880, in an article upon the parasites of American scale insects, the writer showed that international transportation is especially easy and especially desirable in the case of these insects.

In 1883 Dr. Riley succeeded in importing a common European parasite of the imported cabbage worm into this country, where it established itself and has since proved to be a valuable addition to our fauna.

In 1891 the same distinguished entomologist brought about the importation of one of the European parasites of the Hessian fly through the assistance of Mr. Fred. Enock, of London. This parasite maintained itself in this country certainly as late as 1895, but has accomplished no appreciable good, so far as has been ascertained, in limiting the increase of this destructive enemy to wheat.

All previous experiments of this nature were dwarfed into insignificance by the astounding success of the importation of *Novius* (*Vedalia*) *cardinalis*, a ladybird beetle, from Australia into California in 1889. This importation was made, as will be remembered, by Mr. Albert Koebele, an attaché of the Division of Entomology of the United States Department of Agriculture, whose expenses, however, were paid out of a fund appropriated to the Department of State, for the purpose of securing a representation from this country to the Melbourne Exposition. A California man, the late Mr. Frank McCoppin, happened to be at the head of the exposition commission; and, while the late Dr. C. V. Riley was endeavoring in Washington to induce the Department of State to set aside a sum from the exposition fund for the expenses of Mr. Koebele, representatives of the State board of horticulture of California were pressing the same facts upon Mr. McCoppin, the head of the commission. These efforts were made independently and without consultation, hence it happened that after Mr. Koebele had succeeded in sending live Vedalias to California, and after these insects, by their rapid multiplication and voracious habits, had absolutely destroyed the cottony cushion scale in the orange groves of the State, a result which practically saved millions of dollars to California and which attracted the attention of everyone interested in science or agriculture, a most unfortunate controversy ensued between Dr. Riley and the California State board of horticulture as to the placing of the credit of carrying out this wonderfully successful experiment. This controversy embittered the last days of both Dr. Riley and Mr. McCoppin, and was the cause of a disturbance of the formerly pleasant relations between the United States Department of Agriculture and the State board of horticulture of California, which has only recently been overcome.

Following this successful experiment, the same insect, *Novius cardinalis*, was sent to South Africa, where it exterminated the white or fluted scale in that colony. The next year it was sent to Egypt, where it exterminated a congeneric scale insect in the gardens of Alexandria.

The following year Mr. Koebele, still an agent of the United States Department of Agriculture, was sent, with the consent of the Hon. Jeremiah Rusk, but at the expense of the California State Board of Horticulture, to Australia, New Zealand, and the Fiji Islands, for the purpose of securing other valuable beneficial insects for importation into California. Thousands of such insects, comprising a number of different species, nearly all, however, of them Coccinellids, or lady-birds, were sent over and established in California. Several of these species are still living in different parts of the State. The overwhelming success of the importation of *Novius cardinalis* was not repeated, but one of the insects brought over at that time, namely, *Rhizobius ventralis*, has unquestionably ridden many olive groves of the destructive black scale, and is to-day present in many other orchards in such numbers that the scale practically makes no headway.

After this second Oriental trip the relations between the Department of Agriculture and the State Board of Horticulture of California became so strained that the California agents of the Department were given their choice by the honorable Secretary of Agriculture to resign their positions or be transferred to Washington. Mr. Koebele resigned and was soon after employed by the then newly established Hawaiian Republic for the purpose of traveling in different countries and collecting beneficial insects to be introduced into Hawaii for the purpose of destroying injurious insects. It is difficult at this time to ascertain the exact results of the more recent portion of this work. Mr. Koebele's own published reports have dealt less with results than with the details of the introduction of insects, and anonymous newspaper reports are not to be accepted as scientific evidence. Fortunately, however, one of the collectors of the British Association for the Advancement of Science, Mr. R. E. C. Perkins, was in Hawaii during 1896 and made a report on Mr. Koebele's work to the committee appointed by the Royal Society and the British Association for investigating the fauna of the Sandwich Islands, which was published in Nature for March 25, 1897. From this report it appears that the introduction of *Coccinella repanda* from Ceylon, Australia, and China was so successful in the extermination of plant lice upon sugar cane and other crops as to obviate all necessity for spraying. The introduction of *Cryptolæmus montrouzieri* from Australia resulted in the entire recovery of the coffee plants and other trees which were on the point of being totally destroyed by the scale insect known as *Pulvinaria psidii*. Eight other introduced species had at the date of writing (November, 1896) been entirely naturalized and were reported as doing good work against certain scale insects. A Chalcis fly, *Chalcis obscurata*, introduced from China and Japan, multiplied enormously at the expense of an injurious caterpillar which had severely attacked banana and palm trees. Mr. Koebele, when visiting Washington during November, 1898, mentioned a number of other importations of beneficial insects into Hawaii, about which it is as yet too early to speak.

A very recent instance of an international importation of striking value is the sending of *Novius cardinalis* from this country to Portugal, where the white or fluted scale has been checked and in many orchards exterminated in the course of a single year. This importation was made by the writer with the invaluable assistance of the California State Board of Horticulture.

Other experiments in this line are under way. A parasite of certain wax scales, which are abundant and injurious in the South, has been imported by the writer from Italy, with the cooperation of Prof. Antonio Berlese, of the Royal Scuola di Agricoltura di Portici; while an effort is being made to bring from Europe insects which will prey upon the gipsy moth which has been so great a plague about Boston; and other parasites of injurious scale insects in foreign countries are being studied with the purpose of eventually obtaining their introduction into the United States.

AS DESTROYERS OF NOXIOUS PLANTS.

Just as we have shown how important is the role played by insects in the destruction of cultivated and useful plants, it will be easy to indicate their importance as destroyers of weeds and other noxious plants. We need only mention the common and cosmopolitan thistle butterfly (*Pyrameis cardui*), the equally common milkweed butterfly (*Anosia plexippus*), the purslane caterpillar (*Copidryas gloveri*), the burdock beetle (*Gastroidea cyanea*), and the purslane sphinx moth (*Deilephila lineata*) to recall to the mind of the experienced entomologist many other species which do similar work. They are here, as in the former case, perhaps the principal agents in preventing the undue increase of any one species of plant, but as we find here not an effort of man to combat nature, as it were, by increasing the growth and spread of one species at the expense of the others, but the exact opposite, so here also to a degree we find nature arrayed against man, and insects thus play by no means the same part in the destruction of weeds that they do in the destruction of cultivated crops. Nevertheless, they have an important function in this direction, and it is safe to say that the benefit which the agriculturist derives from their work in this way is very great. As long ago as the beginning of the century it was pointed out by Sparrman that a region in Africa which had been choked up by shrubs, perennial plants, and hard, half-withered, and unpalatable grasses, after being made bare by a visitation of destructive grasshoppers, soon appeared in a far more beautiful dress, clothed with new herbs, superb lilies, and fresh annual grasses, affording delicious herbage for the wild cattle and game.

In a similar way Riley has called attention to the fact that after the great grasshopper invasions of Colorado and other Western States in the years 1874 to 1876 there were wonderful changes in the character of the vegetation, the grasshopper devastations being followed by a great prevalence of plants which in ordinary seasons were scarcely noticed. It is true that some of these plants were dangerous weeds, but others were most valuable as forage for the half-starved live stock. Moreover, other plants, and especially short or recumbent grasses, took on a new habit and grew luxuriantly; one species, for example, *Eragrostis poœoides*, ordinarily recumbent and scarcely noted, grew in profusion to a height of 3½ feet.

An important, but not generally realized benefit which is derived from the insects may be mentioned under this head, though not strictly belonging here. Kirby showed, seventy-five years ago, that the insects that attack the roots of grasses, such as wireworms, white grubs, etc., in ordinary seasons only devour so much as is necessary to make room for fresh shoots and the product of new herbage, in this manner maintaining a constant succession of young plants and causing an annual though partial renovation of our meadows and pastures, "so that, when in moderate numbers, these insects do no more harm to the grass than would the sharp-toothed harrows which it has sometimes been obliged to apply to hidebound pastures, and the beneficial operation of which in loosening the subsoil these insect borers closely imitate."

AS POLLENIZERS OF PLANTS.

It can no longer be doubted that cross fertilization is one of the very most important elements in the progressive development and continued health of the great majority of flowering plants, and, indeed, that it is with some almost a condition of existence. Opposition to this view, at no time especially strong since the publication of Darwin's great work, has become feebler and more feeble until at the present it is not worth considering.

Comparative experimentation with self-fertilizing and cross-fertilizing plants, repeated with many species and genera, have shown a superior growth and vitality on the part of those subjected to cross fertilization of such a degree as to leave not a semblance of a doubt, while in individual cases self-fertilization has been scientifically shown to even result in a deterioration so marked that it has been compared to poisoning.

In this condition of affairs it at once becomes evident that the good offices of insects in this direction are of incalculable importance, since it must be plain that of the natural agencies by which cross-fertilization of plants is accomplished insects are far and away the most prominent. Every investigation which has been undertaken of recent years, and activity in this field is increasing by leaps and bounds, has shown the most marvelous adaptations between the structure of flowers and the structure of their insect visitants, all in the line of facilitating or really enforcing the collecting and carriage of pollen by flower-visiting insects from one plant to another. An estimate of the numbers of the species of insects engaged in this work would include the forms belonging to whole families and almost orders, and if we could imagine the race of flower-visiting insects wiped out of existence the disastrous effect upon plant growth would be beyond estimate. I am not prepared to state that insects benefit plants in this way to such an extent as to overcome the results of the work of the plant-destroying species, but if it were possible to compare in any way the results of these two classes of work it is safe to say that the effect would be surprising.

We must, therefore, without going further into detail, place this pollenization of plants as one of the very most important beneficial functions of insects in their relations to man.

AS SCAVENGERS.

Another beneficial function of insects, the importance of which can hardly be overestimated, is their value to humanity in doing away with and rendering innocuous dead matter of both plant and animal origin. This subject has never been discussed without reference to the famous statement by Linnæus that the offspring of three blowflies would destroy the carcass of a horse as quickly as would a lion; and while the exact statement in its details is open to doubt, still it serves to illustrate in a striking way the good offices of insects, and it is certainly true that after the offspring of the blowfly have finished with the horse's carcass this would be left in a much less offensive condition than after the departure of the lion.

There are inhabited regions in which the climate is so dry that dead bodies of animals never become offensive, but by natural mummification remain simply as cumberers of the earth. In such regions insects play little part. Wherever, however, there is sufficient moisture to produce a natural decay, there insects occur in swarms and hasten the destruction of the decomposing mass in a marked degree. Were the bodies of dead animals not destroyed by insects in this way, and, still more, were the destruction of dead vegetation not hastened as it is by the attacks of countless insects, it is perfectly easy to see that the earth would not be inhabitable; its surface would be covered with the indestructible remains of what was once life in some form.

Large groups of insects, comprising many thousands of species, take part in this inestimable work, and it will probably be unnecessary in order to bring about a realization of this value to dwell further upon the subject.

AS MAKERS OF SOIL.

It is a fact not generally realized that insects must take an important part in the changes in the character of the soil which are constantly going on. Occurring in such countless millions, as they do, constantly penetrating the soil in all directions, frequently dragging vegetation below the surface and bringing the subsoil up to the surface, changing the character of the soil humus by passing it through their bodies, and fertilizing the earth by their own death and decay, it is probable that insects are responsible for even more soil change than are the earth worms, which Darwin has placed before us in such an important light.

Insects are found beneath the ground in incredible numbers. Some of them pass their whole life underground, feeding upon roots and rootlets, upon dead and decaying vegetable matter, upon soil humus, and upon other insects. Many of them have their nests underground, although they get their food elsewhere, while others hide their eggs or pupæ underground.

The depth to which they penetrate is something surprising; the minute insects of the family Poduridæ have been found swarming literally by the million at a depth of 6 to 8 feet in a stiff clay subsoil.

AS FOOD AND CLOTHING AND AS USED IN THE ARTS.

In this role insects play an important part. Insects as food and their products as clothing are well known to all. The great silk industry of the world is derived wholly from insects and almost entirely from a single species—the silkworm of commerce.

As food, insects have formed articles of diet for certain savage peoples since the beginning of the human race. Hope, in 1842, catalogued 46 species of insects used as food, and Wallace, in 1854, showed that insects of six different orders were used as food by the Indians of the Amazon. Semicivilized peoples to-day use certain insects as food, as witness the consumption of Corixa eggs by the Mexicans, and a book has been written under the caption Why Not Eat Insects? for the purpose of showing that many possibilities in the way of dietetics are being ignored to-day. M. de Fontvielle, in addressing the Société d'Insectologie, in 1883, expressed regret that the attempts made to popularize the use of insects as food have made so little progress, and said that we ought not to forget the remark of the Roman emperor who said that the body of an enemy never tasted bad, and that the banquet of the society would always lack something so long as there was not placed before them at least some grasshopper farina and fried white worms.

A single insect, the honey bee, furnishes a notable article of food and is the basis of a great and world-wide industry.

As food for poultry, song birds, and food-fish insects are indirectly of great benefit to man. Not only do they provide living food for such animals, but *Corixa mercenaria*, a water bug, is now being imported by the ton from Mexico into England as food for birds, poultry, game, and fish. One ton of these bugs has been computed by Mr. G. W. Kirkaldy to contain 250,000,000 of insects.[1]

In the days of pure empiricism in medicine insects were used extensively, and we have only to mention the Spanish fly to show that they are still of some value.

In the arts shellac and Chinese white wax, as is well known, are insect products, as also are the formerly greatly used cochineal dye and Polish berry dye, the so-called berry in this case being an insect and not a berry.

The last-named instances are all derived from scale insects, a group of astonishing capacity for multiplication, the commercial possibilities of which are by no means exhausted, as I took pleasure in showing in a paper read before the American Association for the Advancement of Science in 1897. It should be noted here also that there is good reason to believe that the manna of the Bible, upon which the Children of Israel subsisted while in the wilderness, was also the secretion of a scale insect.

SUMMARY OF THE HABITS OF INSECTS.

After this general account, arranged under the classes of damage and classes of benefits brought about by insects, it will be well to attempt an arrangement of the subject in a somewhat different manner in order to gain, if possible, some light as to the relative proportion of insects which are injurious or beneficial.

It will be manifestly impossible to catalogue the species or the genera in this way, and it will be obvious that a classification from families will be lacking in exactness, since some of the families are very large in number of species and others exceedingly small; but, taking the groups as a whole, no better and speedier means suggests itself than to summarize the habits by families.

Another difficulty, however, which arises in such a classification is the fact that some orders are in a much more advanced stage of classification than others, and the force which is given to a family as a

[1] Entomologists' Monthly Magazine, August, 1898.

taxonomic group varies with the views of the latest monographer. Nevertheless, taking only the older and generally accepted families and analyzing habits, we find the situation to be as follows:

Of 33 families of Hymenoptera but 2 are strictly plant-feeding; the Cynipidæ, or gall flies, are in the main injurious to plants, but some forms are parasitic; 9 families are strictly parasitic upon other insects; 15 are predatory upon other insects; 2, comprising the bees, have no other especial value in their relations with man than as pollenizers of plants or producers of honey; 3, comprising the ants, are beneficial as scavengers, but injurious in their other relations. It must be remembered, however, that at least 27 of the 33 families are of the greatest value in the cross fertilization of plants, in which work the insects of this order perhaps take the lead.

In the Coleoptera, or beetles, considering 82 families, the insects of 9 families on the whole are injurious and of 23 families on the whole are beneficial as destroying injurious insects; 10 families are beneficial as scavengers and 30 or more, mostly small groups of little importance, contain some scavengers and many neutral forms of practically no economic importance, although certain of them visit flowers; 2 families contain both injurious and beneficial forms, as well as many that are neutral.

In the Siphonaptera, or fleas, the species of the single family are parasitic upon warm-blooded animals.

In the Diptera, or true flies, if we classify the families according to habits of the majority of the species in each, we get, approximately, injurious families, 10; predaceous families, 11; parasitic family, 1; scavengers, 19. In point of numbers of individuals in this order, as well as in the Coleoptera, no doubt the injurious will exceed the predaceous, while in the Diptera the scavengers will probably equal all of the others put together.

In the Lepidoptera practically all of the sixty-odd families are injurious through the damage done by their larvæ to vegetation; but here again it must be remembered—and the same comment holds for many of the Diptera which we have just considered—that the adult insects are among the most active and frequent visitors of flowers and have a great and beneficial effect on cross fertilization.

In the Trichoptera the insects of the single family feed upon aquatic plants and have no economic value except as furnishing food for food-fishes.

The insects of the single family in the order Mecoptera are indifferent in their economic relations, though probably slightly beneficial.

In the Neuroptera all of the 7 families are beneficial through their predaceous habits, with the exception of the Sialidæ, which, since their larvæ are aquatic, may be termed indifferent or neutral, though it has both a beneficial and injurious relation to food-fishes.

In the Homoptera we have 9 families, all of which are injurious, except that here and there a species has had a commercial value, like the lac and dye insects.

In the Heteroptera there are 11 families which are strictly plant feeders; 8 are strictly predaceous; 3 are both injurious and predaceous, while the economic value of 13 is more or less doubtful. Most of these last are aquatic and have some value as fish food.

The insects of the single family of the order Physaptera are injurious.

In the Orthoptera we have 1 family of strictly predaceous habits, 1 which has a mixed food and is partly injurious and partly beneficial, as its species become scavengers; the habits of 1 family are unknown, while in the 4 remaining families the species are all injurious as destroyers of vegetation.

The insects of the single family of the order Euplexoptera are probably beneficial as predatory forms and scavengers.

The single family of the order Mallophaga is injurious, containing parasites of birds and mammals.

In the Corrodentia the habits of the insects of the single family are, on the whole, of little economic importance, though the species are to be classified in the main as scavengers.

In the Isoptera the forms belonging to the two families are injurious.

In the order Plecoptera the species of the single family are practically neutral in their economic relations, although they possess some value as fish food.

All of the insects of the single family of the order Odonata may be called beneficial. The adults are predaceous upon other insects, and are thus strictly beneficial, but the larvæ may in a sense be termed injurious, since they are aquatic and prey upon other aquatic insects which themselves may be food for fishes.

The insects of the single family of the order Ephemerida are of little economic value, except that they are important fish food.

Lastly, the insects of eight of the families of Thysanura are beneficial as scavengers and soil makers, while some of the species of one family are somewhat harmful from the damage which they do in households.

Tabulating the facts thus gained we have the following: Injurious as feeding upon cultivated and useful plants, the insects of 112 families; injurious as parasitic upon warm-blooded animals, the insects of 1 family; beneficial as preying upon other insects, the insects of 79 families; beneficial as scavengers, the insects of 32 families; beneficial as pollenizers only, the insects of 2 families; beneficial as forming food for food-fishes, the insects of 3 families; of undetermined economic importance, the insects of 49 families; families containing both injurious and beneficial forms, 22 families. The totals are: Beneficial, the insects of 113 families; injurious, the insects of 116 families; both, or undetermined, the insects of 71 families.

CONCLUSION.

And now the question is: Are we any nearer the answer to the exact determination of the economic value of the Class than we were at the start? We have, perhaps, gained by this summary a clearer idea of the economic importance of insects, and possibly it may appear by this contrasting method that the benefits derived from them entirely offset their injuries; but we can not, in our present stage of enlightenment (and I say it with all reverence), complacently and piously adopt, with the good old rector of Barham, the view that insects, with all the lower animals, were created for man's benefit, God permitting occasional injuries, to use Kirby's words, "not merely with punitive views, but also to show us what mighty effects He can produce by instruments so insignificant, thus calling on us to glorify His power, wisdom, and goodness."

Contrast with this view the view of Professor Bailey, in one of his charming essays in the volume entitled The Survival of the Unlike: "We are now prepared to admit that this whole question of enemy and friend is a relative one, and does not depend upon right and wrong, but simply upon our own relationships to the given animals and plants. An insect which eats our potatoes is an enemy because we want the potatoes, too; the insect has as much right to the potatoes as we have. He is pressed by the common necessity of maintaining himself, and there is every evidence that the potato was made as much for the insect as for human kind. Dame Nature is quite as much interested in the insect as in man. 'What a pretty bug!' she exclaims; 'send him over to Smith's potato patch.' But a bug which eats this insect is beneficial; that is, he is beneficial to man, not to the insect. Thus everything in nature is a benefit to something and an injury to something; and every time that conditions of life are modified the relationships readjust themselves."

In these words Bailey, with his accustomed felicity, has expressed the situation admirably. Man is but one of the forms of life struggling for existence, at continual warfare with surrounding forms; but by virtue of his surpassing intelligence—itself as gradually evolved as have been the physical characteristics of any given species—he has overrun the earth, has accommodated himself to the most unnatural environments; he has dominated all other species in nature; he has turned to his own uses and encouraged or hastened the evolution of species useful to him or of useful qualities in such species; he has wiped out of existence certain inimical forms and is gaining the control of others. He is the dominant type, and types whose existence and methods of life are opposed to his interests are being pushed to the wall. It is the culmination of a history which has many times repeated itself in past ages. The struggle of other forms of life to accommodate themselves to the conditions brought about by the rapid development of this dominant type is one of the most interesting fields of study open to the biologist to-day. It would seem as if, in man's efforts to make the face of the earth his own, all the complicated elements of life were arrayed against him, and the great and ultimate result of the labor of the biologist in his study of the relations of the different forms of life and the laws which govern their development will be to bring about the absolute control of all other life by man. Thus it is not only the economic worker who looks for immediate results of a practical kind from his labor—the scientific agriculturist, the horticulturist, the economic zoologist, the medical bacteriologist—who should command the respect of even the practical-minded man, but the biologist in whatever field, however restricted it may be, whether he is working toward the understanding of broad principles and general laws, or whether in some narrow corner of research he is accumulating material which will help ultimately to lead to wider understandings—all are working helpfully and practically toward the perfect well-being of the human race.

RECENT ADVANCES IN SCIENCE, AND THEIR BEARING ON MEDICINE AND SURGERY.[1]

By Prof. R. VIRCHOW.

The honor of being invited to deliver the second Huxley lecture has deeply moved me. How beautiful are these days of remembrance which have become a national custom of the English people! How touching is this act of gratitude when the celebration is held at the very place wherein the genius of the man whom it commemorates was first guided toward its scientific development! We are filled not alone with admiration for the hero, but at the same time with grateful recognition of the institution which planted the seed of high achievement in the soul of the youthful student. That you, gentlemen, should have entrusted to a stranger the task of giving these feelings expression seemed to me an act of such kindly sentiment, implying such perfect confidence, that I at first hesitated to accept it. How am I to find in a strange tongue words which shall perfectly express my feelings? How shall I, in the presence of a circle of men who are personally unknown to me, but of whom many knew him who has passed away and had seen him at work, always find the right expression for that which I wish to say as well as a member of that circle itself could? I dare not believe that I shall throughout succeed in this. But if, in spite of all, I repress my scruples it is because I know how indulgently my English colleagues will judge my often incomplete statements, and how fully they are inclined to pardon deficiency in diction if they are convinced of the good intentions of the lecturer.

PROFESSOR HUXLEY'S WORK.

I may assume that such a task would not have been allotted to me had not those who imposed it known how deeply the feeling of admiration for Huxley is rooted within me, had they not seen how fully I recognized the achievements of the dead master from his first epoch-

[1] The second Huxley lecture, delivered by Prof. R. Virchow at the opening of the winter session of Charing Cross Hospital Medical School, on October 3. Reprinted from the London Times in Nature, No. 1510, Vol. 58, October 6, 1898.

making publications, and how greatly I prized the personal friendship which he extended toward me. In truth, the lessons that I received from him in his laboratory—a very modest one according to present conditions—and the introduction to his work which I owe to him form one of the pleasantest and most lasting recollections of my visit to Kensington. The most competent witness of Huxley's earliest period of development, Professor Foster, presented in the first of these lectures[1] a picture of the rapidly increasing extension of the biological knowledge which must have excited not only our admiration but also the emulation of all who study medicine. Upon me the duty is incumbent of incorporating with this presentment the newer strides of knowledge and of stating their influence upon the art of healing. So great a task is this that it would be presumptuous even to dare to attempt its accomplishment in a single lecture. I have decided, therefore, that I must confine myself to merely sketching the influence of biological discoveries upon medicine. In this way, also, will the example of Huxley be most intelligible to us. I must here make a confession. When I tried to ascertain how much time would be required to deliver my lecture as I had prepared it, I found, to my regret, that its delivery would occupy nearly double the time assigned to me. I had therefore to reduce it to about half of its original dimensions. This could only be done by means of very heroic cuts, seriously damaging in more than one place my chain of ideas. If, therefore, you should find, gentlemen, that my transitions from one point to the other occasionally are of a somewhat sudden and violent character, I trust you will bear with me and remember that, if you should take the trouble of reading my address afterward, you will be less shocked than you may be to-day by my statements when they appear in print.

THE BEGINNINGS OF BIOLOGY.

Huxley himself, though trained in the practical school of Charing Cross Hospital, won his special title to fame in the domain of biology. As a matter of fact, at that time even the name of biology had not come into general use. It was only recently that the idea of life itself obtained its full significance. Even in the late Middle Ages it had not sufficient strength to struggle through the veil of dogmatism into the light. I am glad to be able to-day for the second time to credit the English nation with the service of having made the first attempts to define the nature and character of life. It was Francis Glisson who, following expressly in the footsteps of Paracelsus, investigated the *principium vitæ*. If he could not elucidate the nature of life, he at least recognized its main characteristic. This is what he was the first to describe as "irritability," the property on which the energy of living

[1] This lecture by Prof. Michael Foster is reprinted in the Smithsonian Report for 1896, pages 339–364.

matter depends. How great was the step from Paracelsus to Glisson and, we may continue, from Glisson to Hunter! According to Paracelsus, life was the work of a special *spiritus*, which set material substance in action, like a machine; for Glisson, matter itself was the *principium energeticum*. Unfortunately, he did not confine this dictum to living substances only, but applied it to substance in general, to all matter. It was Hunter who first announced the specific nature of living matter as contrasted with nonliving, and he was led to place a *materia vitæ diffusa* at the head of his physiological and pathological views. According to the teaching of Hewson and Hunter, the blood supplied the plastic materials of physiology as well as the plastic exudates of pathology. Such was the basis of the new biological method, if one can apply such an expression to a still incomplete doctrine, in 1842, when Huxley was beginning his medical studies at Charing Cross Hospital. It would lead too far afield were I to recount in this place how it happened that I myself, like Huxley, was early weaned from the pernicious doctrines of humoral pathology.

THE DEVELOPMENT OF BIOLOGY.

When Huxley himself left Charing Cross Hospital, in 1846, he had enjoyed a rich measure of instruction in anatomy and physiology. Thus trained, he took the post of naval surgeon, and by the time that he returned, four years later, he had become a perfect zoologist and a keen-sighted ethnologist. How this was possible anyone will readily understand who knows from his own experience how great the value of personal observation is for the development of independent and unprejudiced thought. For a young man who, besides collecting a rich treasure of positive knowledge, has practiced dissection and the exercise of a critical judgment, a long sea voyage and a peaceful sojourn among entirely new surroundings afford an invaluable opportunity for original work and deep reflection. Freed from the formalism of the schools, thrown upon the use of his own intellect, compelled to test each single object as regards properties and history, he soon forgets the dogmas of the prevailing system and becomes first a skeptic and then an investigator. This change, which did not fail to affect Huxley, and through which arose that Huxley whom we commemorate to-day, is no unknown occurrence to one who is acquainted with the history not only of knowledge, but also of scholars. We need only to point to John Hunter and Darwin as closely allied examples. The path on which these men have achieved their triumphs is that which biology in general has trodden with ever-widening strides since the end of last century—it is the path of genetic investigation. We Germans point with pride to our countryman who opened up this road with full conviction of its importance, and who directed toward it the eyes of the world—our poet-prince Goethe. What he accomplished in particular from plants others of our fellow-countrymen achieved from animals—Wolf, Meckel, and our whole embryological school. As Harvey, Haller, and Hunter had once done, so these men began also with the study of the "ovulum," but this very soon showed that the egg was itself organized, and that from it arose the whole series of organic developments. When Huxley, after his return, came to publish his fundamental observations, he found the history of the progressive transformations of the contents of the egg already verified, for it was by now known that the egg was a cell, and that from it fresh cells and from them organs arose. The second of his three famous papers—that on the relationship between man and the animals next beneath him—limned in exemplary fashion the parallelism in the earliest development of all animal beings. But beyond this it stepped boldly across the border line which tradition and dogma had drawn between man and beast. Huxley had no hesitation in filling the gaps which Darwin had left in his argument, and in explaining that "in respect of substance and structure man and the lower animals are one." Whatever opinion one may hold as to the origin of mankind, the conviction as to the fundamental correspondence of human organization with that of animals is at present universally accepted.

OMNIS CELLULA E CELLULA.

* * * The greatest difficulty in the advance of biology has been the natural tendency of its disciples to set the search after the unity of life in the forefront of their inquiries. Hence arose the doctrine of vital force, an assumption now discarded, but still revealing its influence from time to time in isolated errors. No satisfactory progress could be made till the idea of highly organized living things as units had been set aside; till it was recognized that they were in reality organisms, each constituent part of which had its special life. Ultimate analysis of higher animals and plants brings us alike to the cell, and it is these single parts, the cells, which are to be regarded as the factors of existence. The discovery of the development of complete beings from the ova of animals and the germ-cells of plants has bridged the gap between isolated living cells and complete organisms, and has enabled the study of the former to be employed in elucidating the life of the latter. In a medical school where the teaching is almost exclusively concerned with human beings this sentence should be writ large: "The organism is not an individual, but a social mechanism." Two corollaries must also be stated—(1) that every living organism, like every organ and tissue, contains cells; (2) that the cells are composed of organic chemical substances, which are not themselves alive. The progress of truth in these matters was much retarded by that portion of Schwann's cell theory, which sought to establish the

existence of free cell formation, which really implied the revival of the old doctrine of spontaneous generation. This belief was gradually driven out of the domain of zoology, but in connection with the formation of plastic exudates found a sanctuary in that of pathology. I myself was taught the discontinuity of pathological growths—a view which would logically lead back to the origin of living from nonliving matter. But enlightenment in this matter came to me. At the end of my academical career I was acting as clinical assistant in the eye department of the Berlin Hospital, and I was struck by the fact that keratitis and corneal wounds healed without the appearance of plastic exudation, and I was thus led to study the process of inflammation in other nonvascular structures, such as articular cartilages and the intima of the larger vessels. In no one of these cases was plastic exudation found, but in all of them were changes in the tissue cells. Turning next to vascular organs, and in particular those which are the common seats of exudation processes, I succeeded in demonstrating that the presence of cells in inflammatory exudates was not the result of exudation, but of multiplication of preexisting cells. Extending this to the growth in thickness of the long bones—which was ascribed by Duhamel to organization of a nutritious juice exuded by the periosteal vessels—I was thus eventually able to extend the biological doctrine of *omnis cellula e cellula* to pathological processes as well; every new formation presupposing a matrix or tissue from which its cells arise and the stamp of which they bear.

HEREDITY.

Herein also lies the key to the mystery of heredity. The humoral theory attributed this to the blood, and based the most fantastic ideas upon this hypothesis. We know now that the cells are the factors of the inherited properties, the sources of the germs of new tissues and the motive power of vital action. It must not, however, be supposed that all the problems of heredity have thus been solved. Thus, for instance, a general explanation of theromorphism, or the appearance of variations recalling the lower animals, is still to be found. Each case must be studied on its merits, and an endeavor made to discover whether it arose by atavism or by hereditary transmission of an acquired condition. As to the occurrence of the latter mode of origin, I can express myself positively. Equally difficult is the question of hereditary diseases; this is now generally assumed to depend on the transmission of a predisposition which is present, though not recognizable, in the earliest cells, being derived from the paternal or maternal tissues. But the most elaborately constructed doctrines as to the hereditariness of a given disorder may break down before the discovery of an actual causa viva. A notable example of this is found in the case of leprosy, the transmission of which by inheritance was at one time so firmly believed in that thirty years ago a law was nearly passed in Norway forbidding the marriage of members of leprous families. I myself, however, found that a certain number of cases at any rate did not arise in this way, and my results were confirmed by the discovery of the leprous bacillus by Armauer Hansen. In a moment the hereditary theory of the disease was overthrown and the old view of its acquirement by contagion restored. Precisely the same happened a few decades earlier with regard to favus and scabies. Another instructive condition is that known as Heterotopia, in which fragments of tissues or organs are found dwelling in a situation other than that which is normal to them. This is particularly the case with certain glands, such as the thyroid and suprarenal, but is also known with cartilage, teeth, and the various constituents of dermoids. It no doubt occurs by process of transplantation, the misplaced tissues developing no new properties, but merely preserving their normal powers of growth. The attempt to generalize from this fact and to attribute all tumor formation to this cause carries the idea beyond its proper scientific limits.

PARASITISM AND INFECTION.

With regard to the subject of parasitism, the progress of scientific observation was retarded for centuries by the prevalence of the assumption made by Paracelsus that disease in general was to be regarded as a parasite. Pushed to its logical conclusion, this view would imply that each independent living part of the organism would act as a parasite relatively to the others. The true conception of a parasite implies its harmfulness to its host. The larger animal parasites have been longest known, but it is not so many years since their life history has been completely ascertained and the nature of their cysts explained, while an alternation of generations has been discovered in those which are apparently sexless. Very much more recent is the detection of the parasitic protozoa, by which the occurrence of the tropical fevers may be explained. As yet we have not complete knowledge as to their life history, but we hold the end of the chain by which this knowledge can be attained. The élite of the infectious diseases are, however, the work of the minutest kind of parasitic plants, bacteria, the scientific study of which may be said to date from Pasteur's immortal researches upon putrefaction and fermentation. The observation of microbes under exact experimental conditions, and the chemical investigation of their products opened up the modern field of bacteriology, a science among the early triumphs of which were the discoveries of the bacilli of tubercle and Asiatic cholera by Robert Koch. In connection with this subject three important landmarks require comment. One is the necessity for distinguishing between the cause and the essential nature of infectious diseases, the latter of which is determined by the reaction of the tissues and organs to microbes. Secondly, there is the relation between the smaller parasites and the diseases determined by them. This may be summed up in the general word (introduced by Professor Virchow himself) "infection." But to assume that all infections result from the action of bacteria is to go beyond the domain of present knowledge, and probably to retard further progress. The third point is the question as to the mode of action of infection. It is only the larger parasites whose main effect is the devouring of parts of their hosts; the smaller act mainly by the secretion of virulent poisons. The recognition of this latter fact has led to the brilliant work of Lister on the one hand and to the introduction of serum therapeutics on the other.

ANTISEPTIC SURGERY.

It would be carrying coals to Newcastle were I to sketch in London the beneficial effects which the application of methods of cleanliness has exercised upon surgical practice. In the city wherein the man still lives and works who, by devising this treatment has introduced the greatest and most beneficent reform that the practical branches of medical science have ever known, everyone is aware that Lord Lister, on the strength of his original reasoning, arrived at practical results which the new theory of fermentative and septic processes fully confirmed. Before anyone had succeeded in demonstrating by exact methods the microbes which are active in different diseases, Lister has learned, in a truly prophetic revelation, the means by which protection against the action of putrefactive organism can be attained. The opening up of further regions of clinical medicine to the knife of the surgeon and a perfect revolution in the basis of therapeutics have been the consequence. Lord Lister, whom I am proud to be able to greet as an old friend, is already and always will be reckoned among the greatest benefactors of the human race. May he long be spared to remain at the head of the movement which he called into existence.

ARTIFICIAL IMMUNISATION.

It remains for me to say a word concerning the other great problem, the solution of which the whole world is awaiting with anxious impatience. I refer to the problem of immunity and its practical corollary, artificial immunisation. It has already happened once that an Englishman has succeeded in applying this to the definite destruction of at least one of the most deadly infectious diseases. Jenner's noble discovery has stood its trial as successfully, except in popular fancy, as he hoped. Vaccine is in all hands; vaccination is, with the aid of governments, spreading continually. Pasteur also labored with determination; others have followed him, and the new doctrine of antitoxines is continually acquiring more adherents. But it has not yet emerged from the conflict of opinions, and still less is the secret of immunity itself revealed. We must become well accustomed to the thought that only the next century can bring light and certainty on this point. [Professor Virchow, having referred with pride to the influence of cellular pathology in modern treatment, entailing, as it does, the principle of destroying the focus of disease by early operation, concluded his lecture in these words: May the Medical School of Charing Cross Hospital continue upon the newly opened path with zeal and good fortune. But may its students at the same time never forget that neither the physician nor the naturalist dares to dispense with a cool head and a calm spirit, with practical observation and critical judgment.]

A SKETCH OF BABYLONIAN SOCIETY.[1]

By F. E. Peiser.

The preparation of a history of Babylonian culture is surrounded with so many difficulties that only those but slightly acquainted with its aspects would dare to undertake the task. In fact, the most necessary preliminary studies have been begun only within the last few years. Historical works on the subject show a disregard or ignorance of the elements of the history of culture, while the preliminary works which have appeared lack more or less the bond of interrelationship. It is, therefore, not an unimportant work to give for a part of the history of culture an outline, or skeleton, about which the scattered and disconnected studies, thus far attempted, may rally, and thus make it possible to proceed more methodically in the consideration of individual questions.

For these reasons I have decided to condense several lectures written some years ago into the present publication, which neither claims completeness nor to pronounce the final word. On the contrary, I hope that sharp criticism will be aroused by this sketch, through which the common aim or object may be advanced. As this is really a sketch of the subject I have refrained from citing and collating authorities which are to find their place in monographs to follow; and this also explains why I have taken up society as a unit, and scarcely more than indicated its development. The work is based mainly upon the conditions of Babylon in the sixth and seventh centuries before the Christian era. In going still farther backward, the task is to unravel the close-meshed fabric of Babylonian culture and to study the history of its development along the individual strands.

In the activity of thousands of years the Euphrates and the Tigris have built up from alluvial drift the territory between their arms. Sand and stones, stripped by the melting snow from the Armenian Mountain peaks, have formed deposits which pushed the Persian Gulf ever farther back toward the south and east. Thus we have in the south a province with no mountainous formations, but only plains and hills of sand, with but few stones. The plain is traversed by the two rivers

[1] Translated from Mitteilungen der Vorderasiatischen Gesellschaft, Berlin, 1896.

named, which differ in relative level at two points; at one place the water of the Euphrates flows over and feeds the Tigris, while 100 miles southward an equalization occurs by the reflux of the Tigris into the Euphrates.

If we consider the climate of the country, we find in the south, in the whole of Babylonia, the characteristics of the hot desert climate modified only by the moisture from the rivers. The desert extends up along the Euphrates and spreads far away beyond it over to Mesopotamia. Nevertheless we must form no false picture of the Mesopotamian desert. After heavy rains it is overgrown by vegetation with wonderful rapidity; and the traveler from the Occident is often amazed when, after the rain, the entire desert appears yellow with crocus plants or blue with other growths. At such times the Arabian nomads cross the Euphrates to pasture their cattle, and thus thousands of years ago strife arose between the residents and the invaders, which continued yet further during the historical development.

So far as historical notices accessible up to this time extend, there still remains the sole probability that in the south of the country traversed by the two streams, northward, eastward, and westward from the Persian Gulf, originally dwelt people of a race who used an agglutinative language, were characterized by a compact bodily frame, and were of a Mongoloid type. I do not wish to enter deeply into several much too radical theories concerning the Sumerians and their racial affinities; I would merely like to refer to the fact that I have already in my book, Hittite Inscriptions, called attention to the possibility of a connection between the so-called Hittites, non-Aryan proto-Armenians, and Sumerians, and that the ancient population of Elam might easily be included with these. But even in the earliest times Semites appear to the north of the district bordering on the Persian Gulf. As in the historical development between 2000 and 600 B. C., two invasions and settlements of Semitic nomads can be recorded, in which connection the theory advanced by Winckler concerning the Aramæans and the Chaldeans is especially to be noticed, it is very natural to assume also for these most ancient Semites a nomadic period, which had already ended when history begins to raise the curtain before our searching eyes.

The political supremacy of these oldest Semites introduced racial variations. We may look upon the invading Kassites from the Kassæan mountains as a third element, which also for a time furnished the acknowledged rulers of Babylonia.[1] The second[2] wave of Semitic immigration, the Aramaic tribes, had begun in the time of the Kassu rule, and for centuries furnished the nomadic population of the steppes, against whom the population of the cities were engaged in struggle. The

[1] These Kassites soon succumbed to the higher civilization of the Semites, who, in their turn, stood upon the shoulders of the Sumerians.

[2] Or the third, if it is necessary, as now appears to be clear, to assume, after the Babylonian-Semitic immigration, a Canaanitic one. (I, dynasty from Babylon.)

advances of the tribes and the retreats of the agricultural population were accompanied by ruins of dikes and canals until a strong hand again forced the nomads back and restored the water courses. These tribes became gradually settled and constituted the fourth racial element, as appears from several historical notices and from Assyrian contracts.

Finally, we must notice the pushing forward of the Semitic Kaldi tribes from the south, and the contemporaneous efforts of the Assyrians from the north to obtain the supremacy in Babylonia. But while the preceding four elements composed the basis or foundation out of and upon which ruling classes developed, these two latter parties formed external factors which influenced the social and political life of Babylon.

If we also mention as a potent external factor the Elamite monarchy, which endeavored to play off the Kaldi and the Assyrians against each other in their struggle for Babylon, we have briefly sketched the picture of the inhabitants, their origin, and those of their neighbors who come into consideration.

From these elements and their sediment was formed what we are accustomed to regard as the Babylonian state. We must not imagine an oriental state, however, as being any such firmly-welded whole as are our modern European states. Race feeling operated in a manner altogether different from among us. There the whole life of the State was concentrated about great cult centers. Surface configuration, intercourse relations, and the coincident power of single provinces welded a greater political unit about a cult center. Thus was formed a political organization that perhaps soon after was merged into a larger unit, and left nothing but a name behind it in proof of its former existence. Among these political units we know of Sumer and Akkad, that is the power once connected with Ur, the Kingdom of Babylon; also smaller ones in the north, such as the kingdom of "the four regions" and the Kingdom of Kisshat, of which the cult center is not yet precisely determined but probably to be sought in northern Mesopotamia.[1] Farther away from the proper center lies Elam, which had attained the rank of a State since primeval times. We see Assyria and farther to the north, the proto-Armenian tribes.

The political history of Babylon, even in the earliest times, presents an alternating picture of centralization and disintegration of the empires embodying the centralization. The question presents itself, what could have been the cause which in so remote a period again and again led to the consolidation of a great district, while as yet, in all neighboring provinces, with few exceptions, only a more or less feeble tribal bond could be formed. The answer may be inferred from the following circumstances:

(1) As soon as an individual by reason of the domination of one of the smaller commonwealths had succeeded in restoring the centraliza-

[1] According to Winckler, whose theory we follow, perhaps Harran.

tion after a period of its decay, his main efforts were especially directed toward the restoration of the neglected canals.

(2) During a decline of the central authority the canals became choked with sand.

(3) The Babylonians imagined the period of such political weakness to be a time of anger of the gods, who were deserting the country and giving the supremacy over to its enemies.

(4) The hydrographic conditions of the country of the two rivers were of such nature as in themselves to call for regulation and utilization. For, while the bed of the Tigris in its northern portion is lower than the Euphrates, so that the latter seeks an outlet toward the former during inundations, farther on, at the second confluence of the rivers, it is higher. This peculiarity, which apparently contradicts the fact that the Tigris in that part flows much more swiftly than the Euphrates, is explained by the fact that the former flows in a straight course, and thus has a much shorter distance to traverse than the Euphrates, which describes a large loop. And while the swifter course of the Tigris prevents it from choking its channel, the Euphrates at once covers its domain, its bed, and channels with its alluvial drift whenever a systematic regulation is not kept in continuous operation. It repeatedly fills its own channel, tears away the banks, and reduces the painfully acquired agricultural land to swamp and waste again.

In reply, then, to the inquiry as to the cause of this ever-reappearing centralization, it may be answered that the nomads who first settled in the country of the two rivers were compelled by the hydrographic conditions to regulate the river system; this regulation demanded and developed an administrative center; these conditions gave as a result the idea that the country belonged to the gods; and this idea had force to bring about a real centralization. Ideas continue in activity thousands of years after the conditions out of which they arose have altered. We must not be surprised, therefore, at finding this idea operative under later conditions; we may even use it as a clue to the complicated life of New Babylon.

If, now, we consider the State—I speak, of course, of the individual States in their inward and outward design—we have to regard two factors: (1) The State centers about one focus of cult. For the Orient this cult center is of the greatest importance, since the development of the State is most closely connected with it. (2) The other point of view is the political-economic. The citizens of each one of these States became landowners soon after they had settled in Mesopotamia. They did not cultivate the land themselves, however, but the work was done by serfs or semiserfs, obtained by military expeditions and by purchase. We have private contracts from which we see how boat expeditions were undertaken up the Euphrates against the northern provinces, where the less civilized tribes lived, and in which the contractors, who in this case were merchants and freebooters, undertook to procure slaves.

Among the Assyrians, in contrast to Babylonia, the idea of the State was one of somewhat firmer consolidation. This was caused by the situation of Assyria, wedged between Babylonia and northern Mesopotamia, and by the institution of a mercenary army since Tiglath-Pileser I, which was likewise an efficient factor in the formation of a stronger government than in Babylonia. Nevertheless, the political institutions of the two States are somewhat similar.

The officials were grouped in three orders—those who were occupied with the internal administration; those who watched over the neighboring and tributary States, and the military service that guarded the interests of the State against enemies, and were frequently employed as governors of subjugated States and tribes. The old nobility had, moreover, a direct interest in the State, inasmuch as they preeminently shared the offices among themselves.

The remaining subjects of the King were partly direct and partly indirect, and the latter certainly, in so far as they were, first of all, subordinate to the hierarchy of a temple.

The interest that the individual citizens had in the State lay, apart from the especial interests of the nobles, in the defense against outward attack and in the maintenance of law and justice; and we find, in fact, that the Babylonian State was characterized by a highly developed juridical life. As against the nomadic tribes the domestic militia and mercenaries had to suffice more or less, while against the neighboring powers the tribes themselves were now and again impressed into service.

Of the constitution of the Babylonian State we know very little indeed, and the little we do know is of a negative character, only as the documents give us information of the abrogation of this or that privilege, etc. Besides that, there are preserved to us several charters from Babylonian provinces, which grant certain prerogatives to one family or another. Thus it was legally established that officials of the State should not enter a free territory of this kind; that its inhabitants should not be arrested by the State police nor be constrained to the performance of a number of various villein services owed to the State. We may probably assume that certain cities obtained charters or franchises, but we have only proofs for the investure of foreigners with civic rights first in the time of the Persians, when very soon resounds the cry "Civis Susanus sum" (I am a citizen of Susa), which is important for our appreciation of Cyrus's statesmanship.

From all accounts we must conclude that the Babylonian kingdom was divided into provinces, which were subdivided into administrative districts, within which lay the free family estates. Everywhere but in the free estates or territories the central authority had the right to command arrests, to construct roads, bridges, etc., and to collect stallions for the breeding studs of the Government, or to make arrangements for the maintenance of the studs. The contrast thus made apparent between the rights of the general Government and those of the free estates indicates a period of transition from the feudal to the centralized system. The former is, of course, the earlier, and bears witness to a time when the families were absolutely independent. With the growth of the central power, however, the importance and influence of the old families diminished, and only now and then occurred a relapse into the feudal system, such as, for instance, we learn from the charters. Such privileged territories were generally held in the possession of the old noble families. These also furnished the State with the entire force of its dignitaries, and the high political offices very often descended from father to son.

The citizens were, indeed, as explained above, very different as regards race and legal status, but soon became amalgamated under the influence of the higher civilization.

The Babylonians appear to us enterprising and rather vindictive and litigious, as shown by the numerous lawsuits. In their relations with the gods they assumed the position of equals, and yet at the same time displayed the deepest submission. They made offerings to the gods, but also demanded favors in return. If a person had once committed an offense, however, he could not lament sufficiently before the higher powers.

The family formed the focus of the whole life of the Babylonians, and presented a united and unbroken front. Thus we often find the interests of the State and those of the family in conflict. The sharp separation of the families from one another is easily explained by the former nomadic life of these peoples.

Since, moreover, the individuals of a clan were dependent upon one another, the legal conception was gradually developed that the property of an individual belonged not to himself, but to his whole family. We may thus explain the fact that real estate could be sold only on condition that the other members of the family gave their assent or signified their willingness by their presence while the bill of sale was being drawn up. A further important factor in the development of the family life is ancestor worship and the conceptions resulting from it, which have had the greatest influence in the religious development of the Semites.

The families are, then, as we have seen, the actual units out of which the State is composed. The individual members of the family stand, therefore, in a somewhat freer position as regards the State; they feel that they are first of all members of their own family, from which their connection with the State results secondarily.

The relation of the King to the subject was a double one. (1) The king was the highest representative of the family, which implies the conception of the whole State as one family. Under this conception he was the representative of his subjects in their relations with the gods, and had as such a great authority. (2) The king, however, did not belong to the particular families to which the individual subjects belonged. Therefore family interests in this regard often overbalanced the duty owed to the King.

The individual families in Babylon were often at enmity with one another, and this antagonism had close relations with external politics. All the powers round about Babylon, as the Elamites, Assyrians, and Kaldi, had their partisans in the city. The partisans, however, belonged respectively to the different families. According as the influence of this or that external power predominated in Babylon, one family was played off against another, and their relative possessions were thus shifted accordingly. The two boundary stones belonging to this period—one dated from Sargon, the other from Merodach-Baladan—are very good illustrations of this condition.

The relation of children to their parents was at first a rather patriarchal one, traces of which are found down to the latest times. We have a document from which appears the father's right of protest on the occasion of his son's intended marriage. The son might, indeed, marry against his father's will, but in that case the marriage was not of full validity. On the other hand we find phenomena which result from the further development of the family under the influence of private property rights. Documents dated from about 2300 B. C. refer to adoption to gain laborers. Another kind of adoption was one for the purpose of the fulfillment of obligations imposed by ancestor worship; that is to say, if there were no sons, a slave might be adopted, who should, after the father's death, bring him the customary offerings. We often see that elderly Babylonians intrusted themselves to a child or adopted slave for care and shelter, and made over their property to the child on condition of being supported by him. This custom is to be regarded already as a result of the evolution from collective to individual property rights.

We do not know much about Babylonian education. We can only draw inferences from what Assurbanipal relates concerning his education in the bit riduti (nursery). He states that he was trained in feats of bodily dexterity, and in reading and writing as well. We may probably assume that the well-to-do families had their children taught in a writing school (bit dupsaruti). We have fragments of tablets in which mention is made of a writing house, and there are still extant copies of historical and epic works prepared by writing pupils and then presented to a library.

Trades were diligently practiced, and children and slaves were bound apprentices to master craftsmen. The period of apprenticeship lasted several months or several years, according to the difficulty of the trade. This may have been the case among business men as well, for we find slaves who carried on business for their masters. If the slave proved to be true and clever, he might even be manumitted, but he still retained a connection with the family. Although then, in this case, the idea of the family did not rest upon blood relationship, it nevertheless appeared strong in all directions.

If, now, we compare the inference from the particulars gathered concerning the family with that drawn from the inscriptions, it is shown that what is apparent from the documents was also legally established. For example, sons-in-law could pass over into the family of the wife and become legally associated to the ancestor worship of this family.

As regards the relation of the family to the temple, we must make a distinction between the oldest cults existing within the domains of the individual families and the cults of entire cities. No especial imposts were necessary for the former, since these cults were cared for solely by the members of the respective families. For the latter, on the contrary, special taxes were raised by the king. Occasionally, however, it happened, also, that the king assigned to a temple a whole family, who then had to provide for its maintenance. This probably occurred for the most part after insurrections had been quelled.

In the deportations so often practiced by the Assyrians, the question is always of the noble families, who were thereby placed in a trying situation. They might, indeed, carry on their religious observances even at their place of exile, but were yet obliged to feel themselves in banishment, since, according to its idea, ancestor worship was attached to the graves of their forefathers. Upon the latter point we have but little material; nevertheless, this much is evident from it—that it was not necessary that the graves should be separate. We find, on the contrary, in Babylonia, great sepulchers, whither the dead from whole districts were brought. These sepulchers were naturally the centers for the surrounding district, and individual families connected themselves, respectively, with such a temple and such a sepulcher. To understand the development of the family upon the religious basis of ancestor worship is extremely important in the historical consideration of the Semitic nations, and without this understanding a number of facts can not be explained.

The attempt has been made to prove the existence of a matriarchate also among the Semites, and it has been thought possible to adduce evidence for this view from the oldest inscriptions. This theory depends upon the arrangement of the names of the gods and goddesses and of the ideograms for man and woman. Nevertheless, the fact that in the Sumerian texts the feminine element precedes the masculine is capable of explanation on other grounds.

It appears, however, from the Old Babylonian documents that the wife could conclude independent private contracts; and that she had a legal standing in the family circle as well as before a court of law; that is, she was capable of being her own representative in regard to her own affairs. She had her private property and retained the right to dispose of it. Between the thirtieth and the twentieth centuries B. C.

marriage had already developed in Babylonia upon the basis of individual property rights. Of course there existed at the same time remnants of more ancient modes of marriage, especially when the contracting parties were not of equal caste. Thus we have in the time of the New Babylonian Kingdom—that is, about the seventh century B. C.—a case where a man married a singer. In the marriage contract the death penalty was laid upon the eventual unfaithfulness of the wife; the husband, on the other hand, could put his wife away forthwith on the payment to her of a specified sum of money. In ordinary cases the wife obtained her dowry back if she was repudiated. The children remained in the husband's family. There are, however, remnants of a system where, upon a separation, the daughters followed the mother. The material does not suffice to furnish answers to all questions relative to this subject.

We find women active in trade, industry, and agriculture, and although here, as elsewhere, men were in preponderance, we see them as priestesses in public worship. In the more ancient time they had not only the religious ceremonials to perform, but authority to manage the property of the deity. Women were also much esteemed as prophetesses. Thus there was in Arbela a temple which harbored a great number of prophetesses who were, for example, much consulted by Asarhaddon.

After all that I have said about the position of woman there is no occasion for surprise if we find her in an influential position as queen. An indication of this is the short notice in the synchronistic history that an Assyrian princess ascended the Babylonian throne, and, vice versa, we find in the ninth century the Babylonian princess Samurammat upon the Assyrian throne. The latter had an important sovereign position. We find that she exercised influence upon the internal life of the State whose king she had married, and that she doubled Babylonian influence in Assyria. It is very probable that the legend of the Greeks concerning Semiramis can be traced back to the important position of Samurammat, to whose name, however, whole myths of the goddess Istar have been transferred. Reliefs from the time of Assurbanipal show that the position of the queen was an important one in this time, as well, and a similar conclusion concerning the position of the middle-class woman can be drawn from the documents. * * *

Among the slaves we must distinguish between (1) those that were in the private possession of an individual; (2) the glebæ adscripti, villeins, who in part had arisen from the condition of slaves, in part had been reduced from the condition of freemen into serfdom; (3) the temple slaves, some of whom were purchased and some presented to the temple by pious citizens or by kings; (4) those belonging to the State, captives of war, of whom the greater part passed into the possession of individuals or of the temple. The first and third classes were employed in industries and about houses, the second in the cultivation of land.

We must consider industry in Babylon as highly developed. A large number of certificates of delivery have come down to us, from which it appears (1) that private individuals in Babylonia possessed industrial establishments of the nature of factories, and (2) that the temples were great factories. The slaves were let out to work by their masters, and the hire either given to the slave, in case he himself delivered to his master the profit due from him as slave and maintained himself, or, on the other hand, given to the master if the latter provided for the slave's maintenance. Finally, the employer might give the slave his maintenance and the surplus earnings of the slave to the master. In this case the slave also received something for his labors. Thus the slave might accumulate a little capital. Besides, slavery was not as harsh in the Orient as in the Occident. The slave might buy his own freedom, and could be adopted and become a member of the family and rise to the highest places.

If one compares the employer's expenses when slaves were hired with the cost of free laborers, the latter are in most cases considerably more expensive. This appears to contradict an economic law that work under like conditions should receive equal compensation. I believe that I am able to solve the riddle in the following manner: If a free man entered into service, he had no claim for compensation if he became sick or disabled by his work. The slave, on the contrary, must be maintained by his master, and there were laws according to which whoever hired a slave was required to pay an indemnity to his master during the continuance of any disability incurred by the slave while a servant. Slaves were well protected by these exceedingly humane laws. Everyone who hired slaves belonging to others took good care not to disable them by overburdening their strength. As a consequence, the wages for a slave were smaller than those of a free man, who was obliged to forego indemnity if he received an injury from his work.

As for the glebæ adscripti, they correspond to our tenants by villein service; they had to perform a kind of corvée, that is, they were obliged to work for the landowner on certain days. In most cases, these slaves belonged to a temple and, on this acoount, the temple had also jurisdiction over the slaves belonging to it. Fugitive and refractory slaves were put in chains, but might be released upon the guaranty of a comrade. Documents referring to such cases are extant.

Upon military matters in Babylon little has been handed down to us. The foreign rulers of the successive periods had their own national troops, and probably seldom drafted the Babylonians themselves into military service. These troops gradually became property owners and Babylonians, which explains the clinging to the most ancient custom, namely, that the possession of landed property implied the obligation to furnish soldiers.

From the manner of the origin of the central powers, as sketched above, as well as from the idea that the country was subject to the gods, on the one side, and from the repeated political revolutions on the other, it results, as a matter of course, that out of the tribal possession of the land three forms of ownership must have developed: (1) Temple ownership; (2) State ownership, and (3) only secondarily, private ownership. All three forms are met in the New Babylonian documents, naturally with many variations.

Temple ownership developed out of the proprietary claim upon the whole territory comprised in the district about the temple. Originally a share of the products was yielded on this account to the deity and, therefore, to his temple. Naturally, in the evolution of things, conflicts of rights must have arisen, and thus, even in the oldest documents as yet in the Sumerian language, we see the kings engaged in regulating the temple revenues. Although gradually a partial conversion of the payments in kind into monetary payments took place the former remained by far the most prevalent, even in the Babylon of Nebuchadnezzar and the Persians, as the contract tablets show.[1] Since, especially in years of bad harvests and in times of war, the revenues established by the kings yielded but little, a fixed income was early provided, inasmuch as certain pieces of land were conveyed not merely into the theoretical proprietorship but into the actual possession of the temple, in order that from them the expenses of the temple and the priests might be met.

For the form of State ownership we have only slight indications. If the Assyrian kings restored their possessions to the nobles exiled or imprisoned by the Kaldi, and, vice versa, the Kaldi kings did the same with regard to those exiled by the Assyrians, this restitution might have taken either the form of enfeoffment, of which we have an example in the Merodachbaladan stone of the Berlin Museum, or the form of restitutio in integrum, while it is yet impossible to determine certainly whether State or private ownership was really the form in question. So, in the case of a number of revenues, the question is still open whether we have before us taxes upon private property or rents on account of original State ownership. On the other hand a considerable number of documents in proof of genuine private ownership are extant.

If we consider the three forms of proprietorship from the point of view of revenues, it appears that the temples played a double rôle. If they only took a revenue from certain pieces of ground, they were upon the same footing as the State, which received revenues from the feudal estates, but if they held the estates in actual possession they were analogous to private individuals, who could manage these properties themselves or lease them.

We thus come to the subject of husbandry, which we may now divide

[1] Thence results the arrangement by which the temple farmed out the latter revenues.

into the two principal classes, management by the owner and farming on lease. I premise that this refers only to the property-holding classes. The agricultural laborers, that is, the real producers, were either slaves or peasants, who in their village community had gradually come to a certain condition of servitude, either to the temple or to the State or to the nobles. We have, then, to distinguish between the property-holding classes and the agricultural laborers. Naturally, a large number of modifications of condition arose which bridged over the transactions. But, in the rough, for the time which extends from the ascendancy of Assyria over Babylon to the downfall of the former power, that is, from 900 B. C. to about 600 B. C., one may assume as the greatest difference between the two neighboring States—a difference which was also characteristic of the different relation of power—the existence in Assyria of a free peasant class, in distinction to the existence in Babylonia of an unfree peasant class.

That the development of Assyria from a political point of view was much influenced by its social constitution is to be assumed as a matter of course. If, now, we can logically represent this development, we shall be able to judge of the social background, concerning which little documentary evidence remains. The test will be if the little furnished by the inscriptions agrees with the conception previously gained by us.

Now, it is quite easy to trace how the Assyrian kings gradually formed for themselves a military force suitable for rapid movements, and how the latter, originally, indeed, consisting of natives, became more and more a mercenary force recruited from the free lances of all Asia Minor. It is, moreover, clear from the history of Assur from the time of Asurnaçirpal on, that the internal tranquillity was greater or less in proportion to the exhibition of power with regard to outside countries. This is explained by the fact that, so long as the surrounding peoples could be forced to pay tribute, the standing army was maintained by this tribute, but when from any cause tribute was less freely given, the public burden fell more and more heavily upon the producing classes. When, under the kings of the eighth century, the north and east became less productive because of the pressing forward of Aryan tribes, circumstances must have come to such a pass that a complete revolution resulted, which brought Tiglath-Pileser III, and after him, Salmanassar IV, to the throne. Since this revolution took place in opposition to the ruling dynasty, and since neither king gave himself any trouble to establish his legitimacy by artificial pedigrees showing relationship to ancient legendary dynasties, it is probably to be assumed that they effected their usurpation in the face of the hitherto ruling classes of the military and priests by the help of a third factor. This, then, will also explain the fact that after the counter revolution of Sargon, he and his successors seized upon the old broken threads and relied chiefly upon the soldiery and priesthood. If, then, we inquire concerning this third factor, the only answer is that it is to be sought in the ranks of the townspeople and peasants. It is thus made possible to see in the revolution of 745 B. C. the victory of a revolt of peasants. And this, again, is only to be imagined on the hypothesis that in Assyria a strong peasant class unspoiled by servitude had survived. Always presupposing that development had taken place thus, the ascendancy of Assyria over the surrounding powers may be accounted for as the result of the liberated strength of the nation; and, moreover, the easy victory of Sargon, who accomplished the restoration with the aid of the priests, may be explained on the assumption that many years of warfare had shattered the social condition of the peasants.

There are two factors which make possible a verification of these facts. In the first place, the fact that Sargon, after he had seized the power, regulated property rights in favor of the temples, and, consequently, to the prejudice of the townsmen and peasants, who were probably reduced to yet more oppressive dependence. Thence it follows that, before the restoration, temple ownership had been restricted and relations with the temple relaxed, a fact which accordingly supports my representation of the development. And, secondly, the course of Sargon in the foundation of the city Dur-Sharrukin, inasmuch as he boasts that he has accomplished the expropriation of the landowners in a just manner, seems to indicate that a free peasant class had survived even after the restoration. Under the descendants of Sargon, the evolution of conditions probably tended more and more toward the extinction of this class, and thus formed the social groundwork which, after the downfall of the dynasty, allowed Assyria as well as Babylon to become a Median and Persian province.

Farming on the owner's own account, as we know it from the temple records, was practiced in this manner: Peasants brought their products to the temple storehouses and received for these products receipts from officials appointed for this purpose. It was the same in the case of private owners. It seems, however, as if this kind of management was not very prevalent, or, at any rate, fell into disuse more and more in New Babylon. It was replaced by a system of leasing, which was highly perfected and formed the transition from domestic to commercial management.

I have already stated that the temples farmed out the collection of their revenues; likewise, as with private owners, they rented great tracts of land to contractors. These contractors made a business of renting, inasmuch as they either had the land cultivated on their own account by free or unfree laborers, or leased single pieces again. This sublease was concluded either after exactly the same form as between the first renter and the proprietor or else it was a share rent, so that the property did not give a fixed rent but a proportionate return, which brought a larger or smaller sum according to the result of the harvest. Such farming on shares was also practiced where renters took property directly under their own management from proprietors. The picture of the economic relations of Babylon which we can thus sketch by the help of the contracts, resembles throughout that of Italy in recent centuries, whose political development, indeed, presents besides many striking analogies to that of Babylon. Fully to show this in detail, however, would lead me far beyond the limits of my essay.

Production was directed primarily toward the gaining of the necessaries of life. If the accounts of the Greeks had not already taught us this, the indigenous inscriptions would, immediately upon their decipherment, have shown that the main stress of social activity in Babylonia was placed upon a quite extraordinarily intensive cultivation of the soil. Innumerable are the receipts for the delivery of grain, of dates, of date litter, date wine, sesame, and garlic, which are found cited here, just as in the accounts of the Egpytian pyramids. And on this subject the accounts of the temples, of which the storehouses appear to have ruled the market, speak more clearly than anything else. At the same time, the arrangement is especially peculiar, according to which live stock appears not to have been pastured upon the owner's land nor under the owner's direction, but to have been given into the charge of contractors, who undertook to pasture the herds of various owners, engaged to guard and care for them, and were paid for their services. Here the influx of nomad tribes, with property consisting mainly of herds, and the resulting forms of collective ownership of large tracts of arable land appears to have led very early to certain compromises with the perfected private ownership of real estate.

The consumption of these products, so far as they were not claimed by the producers themselves, must have taken place in the cities; and since exportation could probably have taken place only on a limited scale—for as far as Arabia the neighboring provinces seem to have produced their own grain—a conclusion as to the size of these cities is thereby justified. But then it is unavoidable to assume a highly flourishing condition of industry in these cities; and, indeed, the textile fabrics of Babylon must have been known and celebrated throughout the whole world of that time. The smith's and carver's arts had likewise attained a high degree of perfection. While, however, the materials for these arts—as metals, stone, and ivory—were not produced in the country, but entered it as objects of exchange for the products of Babylon, the material for weaving was in part obtained in the country. There are yet preserved for us many copies of orders by warrant, of which the temple workers received wool from the temple warehouses in order to make cloth of it; and this wool came not only from the possessions of the Babylonians themselves, but doubtless also from the flocks of the nomadic Aramæans, who became, by reason of having a market for their products, ever more firmly attached to the regions of the Euphrates and the Tigris through which they roamed. It is clear how there may and must have arisen through this development conditions which led to antagonism between plain and city, between pasture and agricultural country, and which were then reflected in the political intrigues according as individual parties represented one or the other interest. And it is clear, further, that with the peculiar growth of temple ownership—as I have developed it above out of the idea of proprietary claim upon the soil—antagonisms must have grown up between the priests or representatives of the interests of the temples and the kings as representatives of the interests of the state. Only by means of this insight into its material condition does the history of Babylon, at the time of the dynasty of Sargon, for instance, become intelligible.

I have already, above, emphasized the fact that the cultivation of the land must have been a very intensive one. We see this from pictures which show how water was raised from the canals onto the land by means of hydraulic machines; and we can draw this conclusion from the syllabaries published in the second volumne of the London work of inscriptions, which deal with the various phases of agriculture. Finally we gather the same knowledge from the data of the lists which, drawn up by the temple officials, show what amount was to be raised in taxes alone from the several tracts of ground. These tracts themselves were distinguished according to the kind of cultivation; those where the clods were broken with the hoe were from this called aggullattu—that is, a tool which Tiglath-Pileser I, for example, had used on the construction of roadways in the Armenian highlands. Another kind of tool after which tracts of land were named was the marru, written gish mar—that is, the ideogram for wood, plus the ideogram mar, which is applied to a kind of wagon. Unfortunately the meaning of the word can not yet be ascertained with precision. While marru, in the architectural inscription, is taken by some to mean scoop or bucket, others find in it the meaning wagon tongue. In some of the contracts marru certainly means a kind of vessel. It might not be impossible that there were two meanings in the word: (1) that of the vessel, which would then be referred to in the contracts, as well as in the architectural inscriptions; (2) also that of an implement which might perhaps find employment in transportation as well as in agriculture. I imagine it as a primitive kind of cart or dray, and consider it not impossible that by putting in a plowshare a plow might also have been made from it. Further, lands were designated as zaqpu to be derived from zaqaf, if they were planted with date palms, as pi shulpi, if bordering on water and swampy, as ipinnu, if watered with the water wheel, and as taptu, of which the exact signification as yet eludes definition. Especially in Babylonia the idea of fallow land appears to be lacking, which occurs quite frequently in the Assyrian contracts. Whether here the land actually was or could have been continuously cultivated, without fixed rotation and without pause, I leave undecided.

The individual tracts of land were not computed according to measurements of pure plain geometry, like building plots, but according to measures that had been evolved similar to the German joch, morgen, etc.—that is, according to the gur,[1] or the real unit of capacity, which about corresponds to the German wispel (24 Berlin bushels). According to this, a piece of land was designated by the amount which could be sowed upon it. Naturally, the ancient method must have been perfected under advanced conditions into a fixed measure of extent; it appears that generally a subdivision of the gur—namely, one-tenth of a qa (that is, one eighteen-hundredth of the gur), with the ideographic denotation sha. hi. a, of which I do not know the pronunciation—was fixed as a certain extent of land, which then passed as a unit of measure. It is not yet possible to say anything quite definite as to the size of this unit of measure; Oppert's calculation rests upon false premises. The celebrated assyriologist begins with the unit of linear measure, the ell, and is naturally compelled to construct besides the usual ell a much longer one for land measurement. I believe that I am able to come nearer the truth by a conjecture. If the ground area of a house is measured, it is done by the construction from the linear measure gi=qanu, (reed, i. e. rod)=7 u (u=ammatu=an ell) of a unit of surface measure, namely, gi. u, that is, a surface of which one side was 7 ells, the other, 1 ell long. This construction was carried to such extent that, if there were subdivisions, these were computed according to the surface unit gi. shu. si, qanu, uban (bohen) (mehri haben)=inch; the unit of measure was accordingly divided into parts, of which one side, equal to 7 ells, remained invariable, while the other side was one or more inches in length. It seems to me now, that the procedure was of like nature in the construction of the surface unit for agricultural land. Since u (=ammatu) is to be taken as a fundamental unit, according to the accounts of several documents, this ell of land will denote a piece of land, of which the short side was equal to 1 ell, while the long side, however, extended as far as was necessary in order that one sha. hi. a might be sowed upon it.

We do not learn very much about the real activity of the peasants. The ground was broken, watered after the sowing, guarded against injury from birds or herds, and the fences around the tracts kept in order. The duty of watching and putting the ditches in order is many times emphasized in the documents of lease. About the harvests and the manner of gathering them there is almost nothing to be gained from the inscriptions.

In the Babylon of Nebuchadnezzar II, the main harvest of grain was in Airu (the Hebrew Iyyar); for dates, in Arah-samna (the Hebrew Marheshwan). It is many times stipulated in the contracts that the grain or the dates to be delivered should be brought to the city by boat, and then delivered either into storehouses or granaries on the

[1] 1 gur originally equaled a camel load; imir, the fifth part of it, equaled an ass' load.

quay, or in the house of the purchaser or of the lessor, respectively. That the waterways, which received careful attention, were used for this transportation, need not excite surprise. Since ship asses are many times mentioned, it might seem as though the boats had been drawn from the bank by asses, but that is probably not correct. According to the representations, rafts of the Assyrians were made of wooden frames, under which were fastened skins of rams, closed and water-tight, and filled with air. Navigation is practiced in similar manner down the river even to-day on the Tigris. At the place of destination the wood is sold along with the cargo, and the skins are piled up and transported back upon asses. Such asses might well be meant in the passages mentioned; nothing, however, is learned from this as to the manner of navigation on the canals.

The laborers had, as a remnant of the ancient domestic management, their full maintenance upon the land, and wages beside. If they were free peasants, these wages came from a share in the produce of the harvest. Slaves received their food and clothing from their masters and if they were hired, the employers might give them wages as he did to free laborers; from this they paid to their owner the profit due him from a slave, but might, however, claim clothing from him. Therefore, there are also contracts of hire in which the employer pledged himself to furnish the clothing. It happened, besides, that the employer paid the slave's dues to the master, and guaranteed food and clothing, originally without paying the slave himself anything at all. This would seem to have been the earlier, the other the later form; yet nothing conclusive can as yet be established concerning these important questions.

From the part of the crop which now remained over, therefore, as follows from the conditions detailed above, the contractor's rent was to be paid, the owner's income, and the incumbent taxes and imposts. The rent was either a fixed rent or a share rent. In the first case there was fixed the amount of produce or money to be delivered to the owner. We have several such records, but unfortunately the particulars as to the amount of the rent permit of no inference as to its relation to the returns from the harvests. It was otherwise in the case of the share rents. There it was provided that, after deduction of costs, the proceeds were to be divided equally between tenant and owner. There are several statements in which, moreover, it was agreed who should pay the taxes.

The income of the owners of landed property, among whom the temples also are, of course, to be reckoned, came to them, according to what was said above, in the shape of money or in that of produce. If the latter case prevailed, and this was the rule, there was, naturally, often a hardship for the owner in being compelled to meet his monetary obligations during a period of low prices for grain. On this account, we find an exceedingly large number of texts in which proprietors were forced to mortgage their lands in order to procure money. Nay more, there even exists a document by which a Babylonian in straits mortgaged his harvest on the stalk.

The necessity of obtaining ready money arose not, perhaps, from private needs alone. The public institutions must many times have cooperated in this respect, as in Rome at the time of the Republic. For, although as already recounted at the outset, the temple imposts and even the direct State taxes were still usually delivered in the form of produce, and accordingly little was at first converted into fixed sums of money, there was another consideration which compelled the use of money. And this was the obligation which rested upon the individual estates to furnish soldiers and their equipment, and likewise to provide for their maintenance. This obligation was probably derived from conditions in which the landowner, as yet a peasant himself, held himself in readiness for service in arms in defense of the country. But, indeed, a mercenary soldiery must have developed in Babylon very early, especially because of the changing foreign rule.

Thus we find documents in which money is appropriated directly to serve for the equipment or maintenance of soldiers. Moreover, this explains the occurrence of the designation of qashtu for certain pieces of property; these were just such as had to furnish archers.

Other exactions, to mention these also which, indeed, did not demand a direct expenditure of money, resulted from the public works. For this the organs of administration could constrain the laborers of the temple estates as well as those of private ownership to a kind of corvée, in which their maintenance was furnished by the possessors of the estate.

In Babylon a very important industrial life had developed very early. Of raw products for this, the country had only clay, asphalt and reed in the best quality. All else, for instance, skins of animals, wool, so far as this was not furnished by the tribes which roamed through the country had to be imported. On this account the kings were very often led to undertake military expeditions toward the Amanus, both in order to keep the way open for traffic and to obtain as tribute what they could not buy. Babylon must, indeed, have been a gigantic thoroughfare for the trade between the Mediterranean and the Indian Ocean. About this we can learn nothing directly from the cuneiform inscriptions, though we can learn it indirectly, by inferences, and, moreover, from the Greek authors. One thing is nevertheless clear, that great amounts of raw products lay in the storehouses of Babylon.

Production was divided into the work of trades and that of factories. I call trades the activity of free or unfree laborers, because they were entitled to take apprentices and teach them their trade, an institution which fully corresponds to that of our modern trades. We have to look upon the temple and the industrial establishments of the rich citizens as factories. We have a number of certificates of delivery which show how the raw materials were delivered into the industrial establishments and how the finished products were delivered from them. These indicate how long the laborers worked and what amount of wages they received. As soon as the products of the trades came into demand as objects of luxury, craftsmanship touched the boundaries of art. The conditions in question are similar to those which existed in ancient Egypt. Artizanship is a refinement of what is commonly called trade work, which yet can not attain individuality.

The fine arts were mainly employed upon the royal edifices. Almost every kind of technique was practiced there—metal work (especially embossed work), metal casting, ivory and wood carving, and stone and tile mosaic. The technical perfection of the last was especially remarkable. One is with reason astonished at the blues, partly metallic colors, partly lapis lazuli, which were burnt in upon the tiles for mosaics. The bronze doors of Balawat are a splendid relic of the artistic skill of former times. In considering the stone carving it is striking in how masterly a way the hardest stones were subdued in the most remote times, and that, too, with tools with which modern artists can not work at all. At that time there was as yet no steel. Even the hard basalt was worked with chisels of tempered bronze. Among the minor arts, that of the lapidary is especially to be noticed. We find quite delightful engravings upon the hardest gems. Here, again, is such a technical perfection as could be developed only by the practice of centuries, and which later became lost, so that similar noticeable works could first be produced again only in Italian workshops. Wood carving was employed in the construction of thrones and of little Venus figures in wood. A similar highly developed art appears also in ivory work. Ivory was a much-prized article, for the sake of which the kings often undertook military expeditions, since the elephants were already exterminated on the Euphrates and the Tigris toward the beginning of the tenth century B. C. The ceramics, for which the most excellent raw material was present in all Babylonia, were also remarkable. The clay, which was already washed smooth by the rivers, was ground up so fine that clay writing tablets, for instance, were made of such superlative quality that they could be covered with writing so small as hardly to be read without a microscope.

The Babylonians are our predecessors in the art of printing. We have matrices in clay and in wood. The writing to be multiplied was first carved in wood, then cast in clay, and could then be imprinted upon any number of clay tablets.

A highly developed branch of industry was the art of weaving and embroidery, although we have no specimen of the material. We can form an idea of this art from the representations of the Egyptians and the Babylonians. The Babylonians understood how to weave very thin fabrics as well as the thickest. I myself have seen a clay tablet in London which had been laid upon a piece of linen, so that even now the position of the threads and the excellence of the fabric to which they belonged can be estimated.

The tanner's trade, moreover, was highly developed. This, too, can be judged of only through pictorial representations. According to these, shoes and the harness and saddles of horses were elaborately worked.

Those who carried on industry were partly free, partly slaves; the former received wages, the latter were hired or rented. The owners of the slaves received from the latter, if they were skilled laborers, a fixed income. This must be clearly recognized in the picture of the social relations in Babylon. It is a matter of course, that here the interests of the owners and those of the laborers must have been diverse, and that, therefore, in spite of the immense population of Babylon, its political conditions must have been very unstable, because only the rich—that is, the dwindling minority—had an interest in the maintenance of order. Babylon had never been able to attain the position of Rome, where the Plebs constantly obtained more rights.

As for the instruments of labor in Old Babylon, they were not highly developed. On the other hand, a high degree of technical perfection was wrought out with these poor instruments. Among us the reverse is the case. The tools are very good, but the skill of the human hand has greatly diminished.. Whether a division of labor in the modern sense existed in Babylon can not be yet made clear. There are, nevertheless, a number of facts which would point to it.

According to the representations in the reliefs, the citizens attended public gatherings on state occasions and temple ceremonies, richly adorned and with the insignia which distinguished them as citizens; that is, in flowing garments, with large and artistically made head-dresses, with a seal ring upon the finger, with staff in hand, with girdle and beautifully embroidered leather shoes. In everyday work, on the contrary, we see the same citizens carrying on their business in shirt and apron. Unfortunately, the remains which are at hand come mostly from temples and palaces, and therefore we can form a clear picture only of great state functions.

Several scholars maintain that in Babylon only the temples and palaces are to be considered as great buildings, while the inhabitants lived in primitive huts. This is an untenable view. Portions of foundation walls which belonged to private houses have been discovered, and we are justified in the assumption that Babylon, so long as it existed, made, with its houses, the impression of a great city. One must not forget, withal, that it was an oriental city which required another kind of architecture than that of our great cities. Upon the main streets, which were paved with stone, little outbuildings, such as we still see in oriental cities, which must have served as booths or bazaars, were erected before the houses. There, as in the gates of the temples and palaces, handiwork and traffic were briskly carried on.

Money, the medium of exchange, received its first and best improvement there. It had passed from the conception of barter to the refined conception of value. In even earlier times gold and silver money, and also as subsidiary coinage, copper, bronze, and iron were used. The further the development went the more need there must have been of having the metals in a fixed form and in certain proportions of weight in order that there might be no necessity for weighing the metals each time. It was, therefore, molded into bars and rings. Unfortunately, no such coins have been preserved, but we have written references to them. The unit of value was the mine. This contained 60 sheqels, and the latter had again subdivisions, but these varied. From the two first developments of money arises the third; the use of money as capital; that is, interest-bearing capital. We have, in about 2300 B. C., the transition, as people pledged themselves to work a certain length of time for a sum of money which they must return later.

Exchange was known in Babylon, and there are statements of the changes in value of money. Moreover, the ratio of value between gold and silver was fixed.

This fine development of the relations of value was accompanied by another—the relation of the purchasing power of money to livelihood. A number of documents exist which show that the living expenses of the laborers can not have been very high, and this agrees with what we know of the Orient from other sources. The soil furnishes the necessaries of life without man's having to take much trouble. Consequently, idleness and beggary are nowhere more widespread than in the Orient. Nowhere is industry urged forward in a more brutal way. There are many reliefs from Babylon and Egypt which show laborers constantly driven by blows from a stick; during the transportation of colossal weights an overseer with a club stands behind every three or four laborers.

CONCLUSION.

During the correction of the preceding sketch, which the editor of the Mittheilungen has sent to the press half against my will, but which I will not now withdraw, since otherwise I should be obliged to let it lie for many years to come without finding the time to work it over thoroughly, two gaps came to my special notice, the filling up of which, however, is subsequently to take place elsewhere. The professional position of the priests will probably be described by Zimmern in his contributions to the knowledge of the Babylonian religion; that of the judges will be treated by Kohler in the fourth part of the work published by Kohler and myself upon Babylonian juridical life.

THE EXCAVATIONS OF CARTHAGE.[1]

By PHILIPPE BERGER.

For some time Carthage, which seemed to have been so completely destroyed by the Romans that its very ruins had disappeared, has again been attracting public attention. But a few weeks ago the reports of the Académie des Inscriptions told the tale of new discoveries made in the necropolises of Carthage by the indefatigable zeal of Père Delattre.

The interest aroused by this resurrection of the past has overstepped the confines of the learned world. Tourists hasten to attend the opening of the tombs in the hope of being present when relics of the time of the Magos, the Hamilcars, and the Hannibals are brought to light. The Government, too, has realized the importance of these discoveries for the history of Tunis. Under the enlightened patronage of our resident general and thanks to the subventions of the minister of public instruction and of the Académie des Inscriptions, M. Paul Gauckler, director of the Service des Antiquités et des Arts in Tunis, erected a shed beside Père Delattre's, and in continuing the very line of excavation that has yielded Père Delattre such happy results at the first stroke of the pickax he has come upon a mine richer than any yet worked.

Under a layer of the Byzantine period he discovered a carefully mured up sanctuary of the Roman epoch. In this subterranean chamber, awaiting better times, doubtless, and protected against the zeal of the new religion, had been piled up lists of priests, votive offerings, Mithraic groups, a bull's head bearing a votive inscription to semibarbarous gods between its horns, and marble statues, many of them worthy to appear beside works of the great era of classic Greece. Then, under the Roman, he found in the Phœnician layer, studied by Père Delattre, tombs of the same architecture and with the same contents as those excavated by his predecessor, but singularly rich, containing rings, bracelets, gold necklaces—real treasures, such as would have made the heart of Dureau de La Malle and of Beulé leap for joy.

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[1]Translated from Revue des Deux Mondes, Vol. CLIII, 1899, pp. 658-676.

So each day discloses antiquities surpassing in richness and artistic interest any before known; and if Carthage had yielded nothing but tombs they would have sufficed to give unexpected information, to him who knows how to question them, upon Phœnician art and civilization of the period preceding the overthrow of the queen of the sea by the Romans.

II.

Few spectacles give the impression of the oblivion into which past grandeur falls in the same degree as the ruins of Carthage. Nowhere does Delenda Carthago strike one as such a vivid reality. The Romans acquitted themselves of their work conscientiously, and civilization has completed what the conquerors left undone. The stones of Carthage, after serving in the Roman town, were used, and continue to be used, for the houses of Tunis, and the marble of its columns adorns the cathedrals of Italy and southern France.

From the promontory whence the bay of Tunis is seen in the distance, with the beautiful line of mountains that shut it in on the south, the glance wanders over some earth heaps in which only the trained eye can recognize the site of ancient Carthage. Not even ruins are visible. Far off, toward Tunis, there gleam in the sunlight two lagoons, called the ports of Carthage. They probably formed the inner harbor. The orifices of the great cisterns, the circus and the amphitheater, both of the Roman period, and the long line of aqueducts gliding toward Zagwam, this is all that remains of Carthage. Not far from the sea, in the middle of a tract of land bought by France, on a hillock supposed to have been Byrsa, rises the basilica of St. Louis, at which the antiquities of Carthage were deposited as soon as found. It was the first museum for the purpose and the only one until René de La Blanchère prepared the palace of Manuba to house the finds from excavations made under the management of the Antiquités in Tunis.

It is proper to say that to Cardinal Lavigerie belongs the chief merit of these discoveries. After Dureau de La Malle, who restored the topography of Carthage without ever having been on its site and endeavored to found a society for the exploration of its ruins, and after Beulé, who more recently brought his artistic and archæologic skill to bear upon them, Lavigerie was the first to comprehend the necessity for making systematic excavations at Carthage and for maintaining a permanent station there.

Even before this the Academy, interested in collecting the material of the Corpus Inscriptionum Semiticarum, had charged M. de Sainte-Marie, dragoman of the French consulate at Tunis, to institute some such action. In a little while he had a collection of more than two thousand votire steles of dull sameness, proving, however, that the soil of Carthage still hid Phœnician antiquities. He found, besides, numerous bits of architecture, statues or fragments of statues, all of the

Roman period. He died just after the publication of the texts which science owes to him. After his departure from Tunis the excavations were continued by MM. Reinach and Babelon, and it may be said that the researches called forth by the publication of the Corpus Inscriptionum Semiticarum gave the first impulse to the movement now developing before our eyes.

The Cardinal did not stop at any sacrifice. He paid for the excavations out of his own purse and pleaded the cause of his museum with the persuasive ardor characteristic of him. Fortunately his right hand in this enterprise was Père Delattre, who, with his frank, energetic features, long blond beard, and white robe, is a figure well beloved by all visitors at Tunis. Having been long identified with the place and knowing the people and the locality, Père Delattre was in a better position than anyone else to gather information from the natives and to know at what points to conduct researches.

His investigations, at first limited and rather haphazard, underwent a change as the result of a visit of the Marquis de Vogüé. He graciously placed at Père Delattre's disposal a sum sufficient to enable him to proceed with his work. From that time his resolution was fixed. He conceived the plan of exploring the necropolis in the side of the hill of St. Louis. At nearly the same time a French engineer, who deserves mention, M. Veruaz, in examining the subterranean canal which flows from the great cisterns into the sea, struck upon the first tombs of the Phœnician necropolis of Bordj Djedid, which is crossed by the Roman aqueduct.

M. Héron de Villefosse, who had been present at Père Delattre's first excavations, and had constituted himself his representative at the Academy, kept it daily informed of his discoveries. Yet it neither subsidized nor encouraged him in any way. And thus, little by little, laboring from tomb to tomb, from necropolis to necropolis, he succeeded in determining the site of three great Carthaginian cities of the dead.

These necropolises, extending along the hills that reach from the chapel of St. Louis to the sea, form a semicircle, which embraces the heart of the city, as it were, in the horns of a crescent. Was the whole of the ancient city comprehended within these limits? It must have been very small; but early Rome, also, was of no great extent, and the seven hills are to-day lost in the maze of streets and buildings that form the heart of the modern city. Possibly, too, what has happened to our cemeteries in Paris occurred in Carthage. At first outside the city, they were finally surrounded by it, but were kept in use nevertheless.

In any case, all are not of equal antiquity. The most ancient, called Douimès, from the name of the territory covering it, occupies the most distant point from the sea, not far from the cistern of Malga. It certainly goes back to the sixth, if not to the seventh, century B. C. This age is indicated by the presence of beautiful Corinthian vases, whose date is known to within a century, as well as by the form of certain pieces of earthenware, specially of some rather primitive lamps, resembling deep saucers, the edges of which are pressed together on one side to form a channel for the wick. And this opinion concerning their age is confirmed by the discovery of the pendant to a gold necklace, hardly the size of a ten-franc piece, but admirably engraved with a legend in Phœnician characters of the most archaic type.

The farther from the center, the more recent the date of the necropolis. The least ancient one, yet antedating the end of the Punic wars, forms the right horn of the crescent, where the hills marking the northern limit of the village meet the sea near the Turkish fort of Bordj Djedid. It is especially interesting for the richness of its funeral accessories, in which the influence of Greek art predominates, and for the remains of men contemporary with the supreme struggle of Carthage.

The tombs usually consist of one or more funeral chambers connected by a vertical shaft. They were sunk in the side of the hill to a depth of 8, 10, and even 14 meters. To get at them it was necessary to clean out shafts choked up and completely covered over with dirt heaps, make subterranean passages from tomb to tomb, remove obstacles, and haul aside, even blow up, great flagstones, barring the way to chambers—all at the peril of a thousand difficulties, over which only energy stimulated by the hope of discovery could triumph.

One of the most beautiful tombs of the necropolis of Douimès is the one called by Père Delattre the tomb of Iadamelek, because the pendant to a gold necklace found in it, near one of the skeletons, bears that name—the name of the owner—following a dedication to Astarte-Pygmalion engraved in microscopic but perfectly clear Phœnician characters of great antiquity.

A rock slab, 3 meters long by 50 centimeters thick, covered the sepulcher, and Père Delattre had to cut a passage through it and through 9 meters of earth before he reached the chamber, which he found intact. He describes the sight that met his eyes in these words: "The walls and even the flagstone pavement were overlaid with stucco. This stucco, exceedingly fine and hard, had the white crystalline appearance of snow. The flame of our candles made it gleam in myriad sparkling points. Part of the glazing had become detached, and had fallen on the skeletons in sheets; another part, still unbroken, leaned over like a great piece of cardboard. The density of the stucco was such that under the slightest stroke it gave out a metallic sound."

The glazing did not reach the top of the chamber. Between the stucco and the large stones covering the cave was a space of 19 centimeters, into which a wooden cornice and ceiling had once fitted, but had now disappeared. The imprint of the fibers, and even bits of wood sticking to the rock, could leave no doubt that they had been there. A red thread 5 centimeters below the stones, which must have served as a chalk line to bring the cornice and the ceiling flush with each other, proved with what care this tomb had been executed to the slightest detail. And in the silence of the funeral chamber, in the midst of the usual furnishings of these tombs, the skeletons of two Carthaginians, husband and wife, still guard the remains of the jewels with which they had been adorned.

The tombs vary greatly in their contents, yet nearly all present certain minor objects, which form the obligatory and ritualistic part of the equipment. Near the head, or in a small niche in the wall, are two vials, always the same; a lamp, still blackened with smoke, which probably burnt near the head after the closing of the tomb; then, often, at his side a scent box, which was meant to be held in the hand, but which had rolled to the ground on the crumbling of the bones.

The dead are laid, not in a lateral niche, as in certain other necropolises, but on the ground, in the midst of all the objects with which the respect of their family had surrounded them. There was no coffin. They were lowered through the shaft by cords on a board which served as a funeral couch. Close-riveted handles and large brass nails bear witness to the manner of adjusting those pieces of wood.

Sometimes the body seems to have been covered with two planks, forming a roof over it. In the more recent sepulchers are large pointed amphoræ, and stone chests containing ashes or calcined bones. Often skeletons and cinerary urns are found in the same tomb. This indicates that cremation gradually displaced burial.

Besides the stationary objects, there lay on the ground or leaned against the wall vases of very different forms and dimensions. Sometimes unadorned, sometimes decorated with fringes and black and red circular lines; vases of black Rhodesian earth covered with friezes of animals or scenes from mythology; vases in the form of baby bottles, called bazzula by the natives; large clay amphoræ of rude workmanship; oinochoës, elegantly shaped; alabaster pieces; goblets; vials, on which the Phœnician painter had allowed his fancy free play, some in the form of animals, others representing a crouching woman, or a baboon holding another vase shaped like a frog's head. Ostrich eggs, painted red and yellow, figure extensively in these sepulchers—often several are found in one tomb. In the tomb of Iadamelek an egg, still intact, served both as a receptacle and as stopper to a larger vase. Elsewhere there were only simple rowdelles, rudely painted with human features. Again, there were Egyptian figurines; statuettes; terra-cotta masks; objects having symbolic or religious significance, as well as articles of daily life; small chairs and tables, looking like toys; bone or ivory pieces artistically worked; the whole series of arms and metal utensils; and, finally, scattered around the dead, the remains of his ornaments; innumerable beads for necklaces, of paste, of precious stones, or of gold; rings; bracelets—the whole of life transported to the tomb, the expression, as it were, of the identity of the dead.

All this yields but one thought. The continuation of life in the tomb enables us in a measure to reconstruct what it might have been on earth. For the tomb is the only place that preserves the secrets of life when its last trace and memory have been obliterated from the world of the living.

II.

Till within the last few years it would have been difficult to convey a fairly precise idea of Carthaginian life and civilization. One man has tried, and he could try, because he was a novelist, Gustave Flaubert. Not that his description is literally true, but he was an extremely conscientious student, and to his conscientiousness he joined the gift of correct and vivid perception. Apart from the inevitable exaggerations of romance, which can sometimes be attributed to the authors from whom Flaubert drew his information, Salammbô gives the sensation of forceful, sensual realism. It is cumbered with an accumulation of decorative detail not in contradiction with the glimpses obtained from monuments. Flaubert seems to have had somewhat of a Carthaginian soul.

But one thing he could not bring out clearly, namely, the composite character of this civilization and its Egyptian aspect, strikingly displayed in the costume of the priestesses of Tanit and in the ornaments which, to use the expression of Montesquieu, burdened their superb heads.

The Carthaginians, like all Phœnicians, gave little scope to the ideal. This is shown by the realism of their art and their religion. They were not endowed with a powerful, creative genius; they did not, like the Greeks, create types which compelled the admiration of the world and enriched humanity with new forms. Like all realists, they excelled in the art of imitating whatever struck the eye. They imitated the forms of nature as well as the art-forms of the people with whom they came in contact. The Phœnicians lacked the independence to elaborate from them a new conception of art, distinguished by certain constant characteristics. They were indebted to all their neighbors in succession. Their art, Chaldean when in contact with Chaldean, became Egyptian near Egypt and Greek in the Hellenic period. The Greeks themselves derived the models for their masterpieces from the Orient, but they transformed them by a new idea. The Phœnicians departed from their models only as an interpreter varies what he interprets; they fashioned them in their own image, thereby giving them a something peculiar to themselves. They were great animal painters, also, and under their treatment even the human face assumed a singularly lively expression. From this point of view such a thing as Phœnician art may be said to exist.

The excavations of Carthage have brought out the profound influence of Egypt on this ancient Carthaginian civilization. The sight of the objects unearthed from the tombs transports one to the borders of the Nile. The statuettes have the headdress, costumes, and posture of mummies. The rings and scarabs bear Egyptian scenes, often Egyptian legends. The amulets, which alternate with strands of pearls in the numerous paste necklaces, reproduce subjects familiar in Egypt; the oodja, the sacred eye of Osiris, the grotesque stocky figure of the god Phtah, ankhs (crux ansata), small tables for libations. The uraeus on either side of the solar disk is one of the favorite designs of necklace pendants and earrings, and figures in the head gear of goddesses, in which it forms a kind of high crown, recalling the turreted crown of Ceres.

Doubtless many of the amulets, intaglios, and bibelots, objects which are easily carried from place to place, and are stopped in their wanderings only by the tomb, were actually made in Egypt. But we can not explain as a foreign importation the terra-cotta pieces and the gold and silver jewelry in which an unmistakable imitation of Egypt is accompanied by certain characteristics proving them of home make.

These characteristics appear in certain figurines absolutely Egyptian in the posture of the body and in the disposition and details of the costume. For the graceful forms of the Egyptian women, so pure of line as to seem scarcely human, more massive, less spiritual bodies are substituted. The head is never Egyptian, the protruding eyes are singularly expressive, the root of the nose thick, the lips sensual, the chin prominent. The artist certainly had a Carthaginian model.

Nowhere does this mixture of imitation and subjective, realistic interpretation appear better than in the terra-cotta masks frequently found in Carthaginian tombs, one of the art forms in which the originality of the Carthaginians had freest play. Curiously enough, these masks have holes in the top and sometimes in the sides for suspending them; yet they were not hanging up in the tombs, but laid at the side of the dead. Nor were they meant to cover the face—they were too small.

However that may be, the resemblance to Egyptian funeral masks is striking. Some of the women's masks might be taken for masks of mummies. The hair, rolled up in front over a bandeau, falls in two fine but heavy tresses behind the ears, which are inordinately lengthened by earrings, and spreads out on the chest. But the countenance, the features, the form of the face, denote another inspiration—Greek rather than Egyptian. The whole physiognomy has a refinement and a softness of expression which make of the masks truly subjective works of art. The men who bought these beautiful Corinthian vases and shut them up with themselves in their tombs must have realized the remoter influences at work on this art. It was the art of early Greece, the half Oriental art of Homeric times.

Moreover, the masks are not all made from the same model. A certain course of deterioration is perceptible, a steady diversion from the Egyptian pattern. On some of them the tresses are replaced by small, close curls covering head and shoulders with their wavy mass. Under this abundance of hair falling over the brow are two almond eyes with protruding eyeballs, set deep under long, arched eyebrows. The cheek bones are sunken, the firmly set lips, like the ears, are painted a vivid red, and the neck and breast are dotted red and blue. From afar it recalls the beautiful head of the Cerro de los Santos, recently put on exhibition at the Louvre.

The necropolis of Tharros in Sardinia had revealed the same mixture of native and Egyptian art. The likeness between the relics of Tharros and those of Carthage is so great that most of those from the necropolis of Sardinia could as well be ascribed to a Carthaginian necropolis. But what, in Tharros, might have appeared an exceptional phenomenon peculiar to it the Carthaginian experience shows to have been the rule. The mixture of the two is a fact dominating the whole of the Phœnician civilization of that period in the western basin of the Mediterranean.

The great merchants, responding to the prevailing taste of the people with whom they traded, made whatever had a good sale. At a time when Egypt seemed the type of perfection in art and civilization, they made imitation Egyptian as we make imitation Chinese or Japanese. But they did not work for export only, and their home art was subjected to the same influences. What has happened in our time with regard to China and Japan in a feeble measure reproduces what happened at Carthage. The introduction of Japanese figures, vases, cunningly shaped articles, introduced us to an art which reacted on our ceramics and our decorative painting. Egypt was not nearly so distant from Carthage as we are from the Far East; it had, besides, the prestige conferred by age and the refinement of a powerful civilization. It invaded Carthage on all sides and penetrated everywhere. Egyptian divinities were introduced with the amulets sold at the gates of temples and cemeteries, and, when the Carthaginian represented women or goddesses with Egyptian costumes or headdresses, without doubt they merely reproduced what they saw about them daily.

It more and more appears that this somewhat servile imitation of nature—rude, yet close, biting, and somewhat satiric—was the distinctive trait of Carthaginian art. The mask of a man, the only one of its kind, is a striking example. The oval, bony face is encircled by whiskers, leaving mouth and chin uncovered; the prominent nose, as well as the ears, are pierced with a gold ring. The eyes have an oddly mocking expression; they are painted white, the eyeballs and eyebrows black. The short, crisply curled hair meets the brow in a straight line from ear to ear, and wherever the skin shows it is highly colored in red. Several of the engraved stones of exquisite workmanship, in which Greek influence is perceptible, present the same type of man with crisp curls, side whiskers, and smooth-shaven chin. Whiskers worn by Greek warriors had appeared on some of the most ancient specimens of Greek ceramics, but the nose ring, the *nezem*, on a man—what a curious thing, what a revelation it is. That is the way the old Carthaginian sea wolves must have looked.

There are other masks in these tombs; not portraits, but veritable grinning masks. One represents an old man, with smooth-shaven, wrinkled face, the nose hooked, the bald forehead receding. The laugh that draws his features makes his cheek bones prominent, and forms a double, funnel-shaped circle of folds about his mouth. The eyes are represented by balls shaped like reversed crescents, and on each cheek bone is a slight application of pastel. Another mask, both grotesque and sinister, has rarer strength of expression. The low, narrow forehead bulges out; the cheek bones are sharp and prominent; the nose, with base deeply imbedded in the cheeks, follows their movements; the eyes are made by two large holes cut through the thickness of the mask, and the mouth, whose lips form a bourrelet, recalling the Greek tragic mask, by another; between the eyebrows is the disk, inclosed in the reversed crescent, and the whole face, with its irregular features, changes expression with the angle under which it is seen.

The Carthaginians were endowed with feeling for caricature. Realism—that is, the nonidealistic reproduction of nature—induced a heightening of her grotesque aspects, an exaggeration of all her features. This bias betrays itself everywhere in their portraiture—on their engraved stones and on their statuettes. They liked to depict man in attitudes lacking the nobility of Greek figures, and they liked to depict monkeys.

This feeling for caricature comes out even in their divinities, fat, stocky dwarfs with lolling tongues, sometimes disgustingly nude; those horned devils' heads, and those monstrosities made up of parts of animals different in nature and sex. Their Hercules, the prototype of the Greek Hercules, has the Greek hero's strength and other attributes, but is a grotesque dwarf, who struggles with cranes, larger than himself, and, though a dwarf, is yet terrible. They had a perception of the contrasts and mockery of things human, and were the first to represent their tragic and terrible aspect.

Possibly this is the most original side of their art, the side that obtruded itself on the people with whom they came in contact. Certain by no means unimportant gods of Egypt, Bes, Set, Phtah, as a dwarf, and all the grotesque and malevolent divinities of darkness and evil, introduced at an early period into the Egyptian Pantheon, seem, if not directly of Phœnician origin, at least to have sprung from the ancient fountainhead of civilization whence Phœnicia came forth, and of which she has in a measure preserved the classic type.

This explains the coarse idols, the fetiches, the stone gods, objects of Carthaginian fear and adoration. In the necropolis of Douimès was found a kind of hard, blackish pebblestone, strange to the environs of Carthage, of the shape of a flattened sphere. On one side it bears rude tracings, large round eyes, a nose, ears, and a mouth inordinately wide, whose straight line cuts the lower part of the face—the grinning face of the man in the moon. This stone is certainly a bætylus; that is, an idol, one of the stones inhabited and animated by a divinity, which were called by the Greeks stones with souls. Compare it with those beautiful Carthaginian masks, representing the head of a goddess surmounted by a crown of serpents, pure of line, refined and dignified, and the contrast fairly grates on one. On the one hand, Greek art at its noblest brought to bear on an Oriental conception; on the other, coarseness and barbarity. However, this head has a certain amount of expression, and the same expression is found on a similar stone bearing a mysterious inscription on the reverse side. It is found, also, on ostrich eggs with human features coarsely painted in blue, red, and black. One realizes that this god devoured children.

The jewelry and the articles in precious metals help to complete the picture of this strange civilization, a curious mixture of refinement and barbarity, thoroughly impregnated with Oriental ideas, of which the excavations at Carthage disclose new manifestations every day. The jeweler's art does not pretend to embody a high conception of the ideal. Jewels are the accessories and natural complements of beauty; they are often substituted for it among peoples who rate richness of form above beauty of feature and purity of line. To judge by their variety, their perfection, and the place they hold in these sepulchers, they seem to have been one of the favorite forms of art among the Carthaginians; yet even they show this mixture of borrowed and native art. There are scarabs, amulets, fragments of purely Egyptian necklaces, along with pieces of jewelry in which, by the side of an inspiration from foreign sources, the native skill of the Carthaginians in such work asserts itself.

The Phœnicians were always marvelous workers in metal. When Solomon wanted to decorate the temple of Jerusalem and his palace he requested the King of Tyre to send him artists. It is probable that the jewelers of Sidon played the same rôle in Greece. M. Naville has recently shown that they practiced their art as far as Egypt. At all events, the products of their industry flooded the markets of the Occident, where they took women in exchange for their gold necklaces, their bracelets, and, above all, their bronze and silver cups in repoussé, decorated in long circular designs with scenes from the chase, processions of wild or domestic animals, contests between gods and fantastic beasts—a résumé of the religious conceptions which developed into the mythology of the Greeks.

The cups that are found in Greece, the Isle of Cyprus, and even Italy have not yet been discovered in Carthage. The soil has not the sandy dryness of Egypt, which preserves relics buried in it; nor has it been overlaid with a stratum of cinders such as at Pompeii enshrouds and petrifies a whole civilization in its perfection. The cedar wood which covered the dead or formed the ceiling of their tombs has fallen to dust, and only the handles by which they were lowered on their funeral couches remain.

Even bronze and silver have been consumed by rust, yet these metals must have held a large place in the equipment of the tombs. There are remains of weapons—small hatchets, spear heads, cutlasses, hooks, shovels, and tongs; also, thick copper cymbals, bells, mirrors, and, above all, beautiful bronze vinochoës, which, being more massive, have resisted better. One of them, entirely of gilded bronze and of rare elegance of form, is provided with a handle rising in a graceful curve over the neck. The junction of neck and handle is made by a square piece, from which the head of a calf, surmounted by disk and uræus, stands out in relief. On others the handle, artistically wrought, has, at the points of attachment a beardless head above and below a bearded head with the features of a Silenus.

Gold alone has not been attacked by time. It has resisted even the wear of the waves of the sea. The coast of Carthage, on a level with the promontory of Bordj Djedid, is veritable gold-bearing sand, mixed with which are found, now small grains of gold, now links, rings, and other minor objects. As M. Gauckler has demonstrated, the presence of this gold is due to the collapse of the caves of the necropolis sunk in the cliff.

Only Etruscan jewels or the art of a Castellani can give an idea of the method by which Carthaginians worked the gold and produced jewels whose delicacy still charms. These bits of necklaces, these pendents and earrings, are made by placing tiny balls of gold close to each other to form links, beads, and cubes. The delicacy of effect obtained by the application of this milled work to massive gold can not be described. The earrings, especially, are small masterpieces of jewelry. Sometimes they end in long gold beads; sometimes they are shaped like lanterns, with a pyramid of gold grains rising in the middle. These jewels are not peculiar to the necropolis of Bordj Djedid. The most beautiful, possibly, came from the more ancient tombs. In one of the latter M. Gauckler quite recently discovered a body wearing a gold finger ring with four baboons engraved on the chaton, in the left ear an earring with the symbol of Tanit, around the neck a large necklace of massive gold, composed of 40 pieces of various shapes symmetrically disposed on either side of a central brooch, which consists of a turquoise crescent falling over a hyacinth disk. Another necklace of silver completed the adornments.

A curious terra-cotta statuette enables us to understand how these jewels were worn. It represents a goddess seated, her mantle wound about her bust in the shape of a disk. The headdress is high and decorated with a triple row of roses, disks, and laurel leaves; long shell-shaped earrings hang to the bottom of the cheeks. Three ample necklaces drop over the breast and entirely cover it. The first, which clasps the neck, is composed of beads; the second, spread out like a fan, of pieces as large as olives; the third, of still larger disks. This must have been a typical costume, for it reappears on several nearly identical statuettes. On one found at Tharros the breast of the goddess is entirely covered with six rows of jewels, each with a different motive.

So little by little the tomb gives up all the tokens of a civilization which caused the fortune of Rome to tremble in the balance, and which has left a name in history for the brilliancy of its wealth and for its determined energy in seeking to control the markets of the ancient world.

III.

The silence concerning the names of those buried in the tombs is surprising. In Egypt the chambers of the hypogea and the pyramids are covered with inscriptions ranged along the walls. The Greeks and Romans inscribed the name and title of the dead on slates to keep their memories alive. Here there is nothing of the kind. Oftenest the sepulchral chamber and even the sarcophagus bear no mention of him who is buried there. On some rare mortuary plaques appears the dry legend, "Tomb of such a one, son of such a one," and that is all. Not one has yet been found in place. The inscriptions multiply only as cremation is resorted to. Then funeral urns begin to be covered with legends, printed in ink, most frequently with the name of those whose ashes they contain.

It seems, however, that the silence is breaking; the very tombs are beginning to speak. Recall that little gold medallion found in one of the most ancient tombs of Carthage, with a dedication to Astarte-Pygmalion, followed by the owner's name: "To Astarte-Pygmalion, Iadamelek, son of Paddaï. Pygmalion protects whom he protects." Is it not interesting to find the name Pygmalion, brother-in-law of Dido, who plays so great a rôle in the history of the foundation of Carthage, associated in this ancient tomb with Astarte?

At the end of last year Père Delattre made a discovery in the necropolis of Bordj Djedid, which suffers no diminution in interest through pertaining to less ancient times. In clearing out a shaft sunk vertically into the ground to a depth of 14 meters he reached a mortuary chamber. Here, in the midst of an obstructing mass of débris, he found beside chests containing skeletons and the usual funeral accessories, first, four little stone sarcophagi, from 40 to 50 centimeters long, inclosing only calcined bones; then in a corner to the left of the chamber, under the ceiling, another sarcophagus of the same dimensions, but bearing on its lid the full-length portrait of the dead, engraved on a block cut out in relief in the thickness of the lid to reproduce the contours of the body.

The body lies extended to its full length, like the figures on the flat tombstones of the Middle Ages. It is an old man with a long beard and hard features, his forehead bare, his upper lip strongly curved, his turbaned head lying on two cushions with tassels. His right hand is lifted in sign of adoration; his left holds a scent box. On his breast he wears a breastplate of the shape of a Maltese cross, its points extending to the shoulders. A band reaching from the right shoulder to the hem and, widening from the shoulder on, makes a brocade on the robe, which laps over the feet in large folds. On the vertical edge of the lid behind the head is the legend, in beautiful Phœnician characters, "Abdmelqart, the Rab."

Another funeral chamber at the bottom of the shaft contained a second sarcophagus with a human figure of the same dimensions, less archaic in style, possibly, yet wonderfully lifelike. The pose is the same, but the body, instead of being engraved, is sculptured in high relief on the cover, like the knights and ladies on their stone coffins. The expression is calm and collected; the hair and beard are carefully curled. The sculptor's work, somewhat weak and betokening no great antiquity, is so finely done that all the details of the costume can be studied. A large band, a sort of cap, caught at the shoulder by a clasp, falls to the middle of the leg. As in the other sarcophagus, the right hand is lifted and the left holds a scent box on a level with the breast.

Contact with these great dead, who possibly played a rôle in the struggles of Carthage with the Romans, is deeply impressive, and one is tempted to question them. Who were they? Were they all of equal dignity? What office was denoted by that title Rab, which signifies "prince" or "grandee?" Doubtless it meant members of one of the grand councils of Carthage, one of the principes mentioned after the suffetes on inscriptions. The dedication of the temple of Astarte and Tanit, found at nearly the same time on the top of the cliff overlooking the necropolis of Bordj Djedid, mentions on the list of eponymic magistrates, between the suffetes and the high priest, the same personages with the same titles. And who knows but what the soil of Carthage may some day yield a list of the Rab, or, indeed, of the suffetes—a list which would do for Carthaginian history what the discovery of the Consular Fastes has done for Roman history?

Meanwhile every day adds to our knowledge, or, rather, diminishes our ignorance, and every day we are permitted to penetrate deeper into this life beyond the tomb, the continuation of terrestrial existence. Some few weeks ago M. Gauckler discovered near a shaft one of the small lead leaves rolled up, which were slipped into the tomb, and bore imprecations to restrain certain spirits or conciliate them; only the inscription was not Greek or Latin, like that of all hitherto known, but in Phœnician characters. Thus beliefs supposed to have been peculiar to Egypt or Greece turn out to have been Carthaginian as well.

Another inscription, the latest discovered, of which Perè Delattre has just sent a photograph, will possibly furnish some light on this point, when entirely deciphered. It is a funeral inscription of rare interest, in which the author traces his genealogy back to the seventh or eighth generation. The genealogy is accompanied by honorary titles, of whose import we have as yet only a faint idea. After giving his descent, the Carthaginian at great length commends the monument that he has erected and possibly his titles also to the favor of the gods, and appears to invoke the benediction of the sun god on his mortal remains.

At all events, it is not a slab for merely identifying the dead, but a monumental inscription intended for an edifice over the tomb. It seems, then, that the necropolises whose traces we seek underground were covered, according to a frequent usage among Oriental peoples, with monuments which kept a place for the dead among the living. Upheavals—the law of history—have swept these monuments away, but one inscription has been left as proof of their existence. Others will be found; the discoveries that have succeeded each other for some years without interruption in the domain of Carthaginian antiquity permit us to hope for more.

We must not shut our eyes to the fact that we are witnesses of an event of greater archæologic interest than any that has taken place for some time. It is the beginning of the resurrection of Carthage. If for no other reason than this, we ought to congratulate ourselves upon the conquest that has put Tunis into our hands, and gave a powerful stimulus to research by handing this historic ground over to science as a field for exploration, such as, comparatively speaking, Egypt was at the beginning of the century. The minister of public instruction thoroughly realized its importance when he instituted the North African commission. It instigates discoveries and centralizes them; serves as a bond between the direction of the Académie des Antiquités in Tunis and the officers of our topographical survey and the scholars to whom it intrusts missions, and effectively coordinates all these efforts in a way beginning to show good results.

Every civilization depends on those that have preceded it. It puts to good use the lessons of things. The sites of towns, ports, roads, the administration of water ways, the customs of the first cultivators of land, the laws that governed their development, are so many signboards for later occupants. The knowledge of Carthaginian civilization and of times preceding it is necessary to understand the development of Roman colonization. It even explains for us to-day certain predominant traits of that mixture of peoples unified by Islam. In this study nothing can be neglected, for often things apparently valueless suddenly assume unsuspected importance. I do not speak of the pleasure experienced by the lover of science, when he questions ancient times, reconstructs what is no more, follows up the genesis of nations, discovers points of contact between civilizations to all appearance widely separated, and explains the present by the past, thereby fully realizing the bond that unites all things.

THE TRANSPORTATION AND LIFTING OF HEAVY BODIES BY THE ANCIENTS.[1]

A PROBABLE METHOD.

By J. Elfreth Watkins, C. E.
Curator of Technology, United States National Museum.

The ability displayed by the ancients in transporting heavy objects from place to place, and in raising them many feet above the surface of the ground in the construction of temples, palaces, and pyramids, has long been a source of wonder. It may, indeed, be truly said that the engineers of the present era would find it difficult to perform similar feats, even when aided by the most improved appliances devised through the ingenuity developed in this inventive age.

So impressed with amazement at the achievements of the ancient architects have trained archæologists become that not infrequently the opinion is expressed that these men, whose work has withstood the ravages of scores of centuries, must have been aided by well-devised machines, possibly operated by one or more of the generated forces.

Notwithstanding these conjectures, in the many careful and thorough explorations made in late years the remains of no hoisting machine have thus far been discovered, nor has there been found, either in the Assyro-Babylonian cuneiform inscriptions or in the Egyptian hieroglyphics, an account or description of the processes employed by the ancients in lifting heavy masses to extraordinary heights. In fact, no equivalents for the words "derrick," "pulley," "winch," etc., have yet been identified in these ancient records to encourage the belief in a seaculo sapienti.

It is the purpose of this paper to explain how many of the edifices now regarded as remarkable could have been constructed by primitive tools and simple methods. Eight years ago, while the writer was making the investigations which led to the publication of a paper entitled "The beginnings of engineering," presented before the American Society of Civil Engineers, access was had to many drawings and photographs of ancient mural paintings and carvings in relief in the

[1] From Cassier's Magazine, December, 1898. XXXIII.

collections of the United States National Museum and in the great libraries of Washington and New York City.

While several pictorial remains are in existence, showing how, by the aid of sledges, rollers, and levers, huge images of stone were moved over ground from the quarry to the building under construction, nothing has been found to show how these heavy masses were lifted into position. In examining the photographs referred to, it was noted, especially in the pictorial representation of Assyrian and Egyptian remains, that many figures are represented in various attitudes carrying something in baskets or bags. It occurred to the writer that this "something" was clay or other kind of earth, and a method of lifting heavy bodies into position suggested itself, in which the sledge, the roller, the level, and the inclined plane, made of earth, were the only mechanical powers necessary to be utilized, no pulleys, cranes or other machinery being employed.

From the earliest times the erection of embankments of earth has been carried on by savage nations and primitive peoples. The earthworks left by the mound builders in America and Europe are conspicuous evidence that the digging and carrying of earth was practiced on a large scale in many localities, far distant from one another, centuries ago.

Let us see how, by the aid of inclined planes of earth, the huge stones used in the construction of dolmens or cromlechs could be put in position by the use of primitive appliances. The stone posts could be moved to the desired place and erected in a vertical position in the manner indicated by the several accompanying drawings. In the illustration (Pl. I) figure 1 shows the stone post lying flat and supported upon rollers; figure 2 shows two piles of earth dug from the pit in which one of the posts is to stand. The stone slab can be rolled up the inclined plane and tilted into position, and, by the use of levers and pry bars, be made to stand upright; and when the second post was erected by a similar operation, and the space between the posts and around them filled with earth, the top stone or lintel could be placed in position after being elevated to the desired height on another inclined plane, made of earth, as shown in Pl. II. These operations being completed, the earth could be returned to the pits from which it was dug and the surface of the ground leveled.

Since these lines were written the author has received the following communication from Dr. William H. Dall, of the United States Geological Survey:

"During a visit to the island of Jersey (Channel Islands) in 1878, while wandering over the hills, I noticed among many dolmens scattered about one which seemed to have never been finished. The sides stood erect, and one enormous roofing slab had been laid in place, covering about half the cavity at the inner end. Behind it and against the erect slab, forming the end of the chamber, was an inclined plane of earth, beaten very hard, and extending from the level of the uprights

Fig. 1.

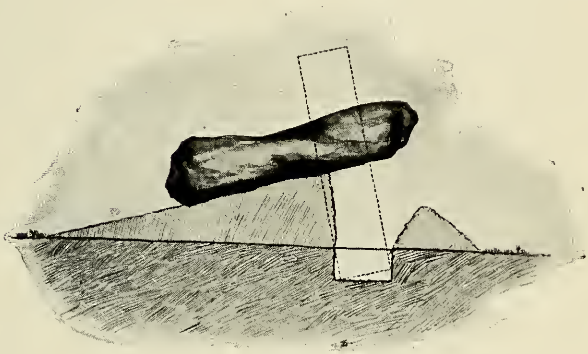


Fig. 2.

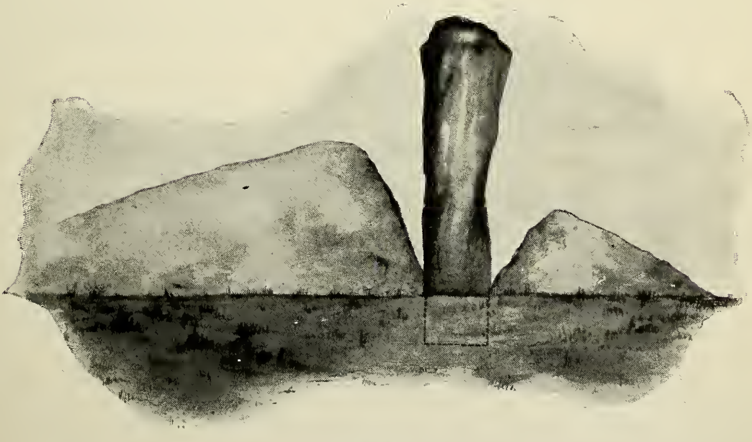


Fig. 3.

ANCIENT METHODS OF MOVING HEAVY BODIES.

to the general level of the soil. Here was a clue to a very simple explanation of what had often puzzled me—how the prehistoric people without tools could have raised such heavy weights as the roofing slabs of the dolmens to the positions in which we find them. It was evident that cords and rollers, with a sufficient number of sturdy savages, would have been amply sufficient for the purpose in the case before me. The thorough manner in which the clay of the inclined plane had been consolidated was evident when it was considered that the denudation of it by the elements during unknown centuries had been insufficient to noticeably reduce its level or conceal its evident purpose."

The construction of the Egyptian pyramids, for centuries a matter of wonder, could have been performed by similar methods. Let us suppose that each of the stone blocks used had a rectangular base, being half as thick as wide, and that they were moved from the quarry to the pyramid in the direction indicated by the arrow in figure 1, block No. 1 being first placed on rollers and moved into position. The stone blocks numbered 2, 3, 4, and 5 could then have been transported along the surface of the ground in the same manner, and so could the other stones in the same tier, which are not shown in this view. An embankment at a 20 or 30 per cent grade (see section *A*) could then have been constructed by carrying earth from pits beyond the continuation of the boundary lines of the base of the pyramid. Over the surface of this plane, extended toward the quarry, the second tier of stones, of which blocks numbered 6, 7, 8, and 9 are visible, could then have been put in place; embankment *B* could then have been constructed, blocks numbered 10, 11, 12, and those behind them being put in place; and so on, by the aid of the additions to the embankments, *C*, *D*, and *E*, the remaining stones could have been put in position.

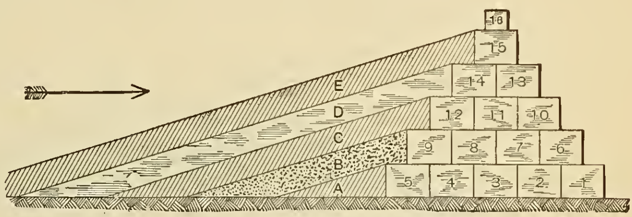


Fig. 1.

When the pyramid was complete the earth could have been removed from in front of it, the pits filled up, restoring the original condition of the surface of the ground, leaving no hint to gratify the explorer forty centuries after the work was done.

Let us see what labor this method would have involved in the construction of the pyramid of Gizeh, the largest of its kind, which is approximately 150 yards high and 250 yards square at the base. As is well known, in building this pyramid, which is located 3 miles south of Cairo, two kinds of stone were used—limestone and red granite. The limestone was quarried at El Massarah, 45 or 50 miles from Gizeh, while the red granite was brought from Assouan, near the first Cataract, over 500 miles. Both of these quarries were located on the River Nile.

In the foreground of the illustration (Pl. III) are to be seen rafts laden with stone blocks, brought from the quarries. Upon the sloping embankment blocks are being drawn on sledges, perhaps equipped with rollers, to the highest point to which the structure has been built, the inclined plane being gradually made longer and higher with earth brought from the pits on the right and left. The highest embankment necessary when the workmen reached the top course, assuming that a 20 per cent grade was adopted, would have been 750 yards long, containing about 7,500,000 cubic yards, if the sides of the earth embankment would stand at an angle of 30 degrees, which is not at all improbable.

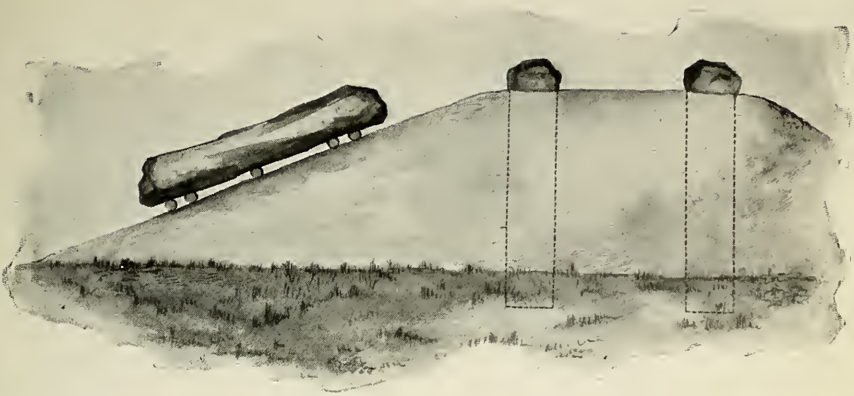
Assuming that one laborer could have placed 2½ yards (about 20 barrow loads) of earth on an average each day on this embankment, 10,000 men could have built it in twelve months of twenty-five working days. It is stated that 100,000 men were employed for twenty years in the whole work, so that, according to this calculation, the construction of this embankment would have occupied only a small portion of the total time consumed.

The false work to support the walls of the interior chambers of the pyramids could also have been made of earth rather than of timber. It should be remembered that heavy lumber for scaffolding must have been brought over long distances and that the framing and erection of any structure of sufficient strength to bear heavy weights would have required more skill and knowledge than the building of the pyramid itself by the method above described.

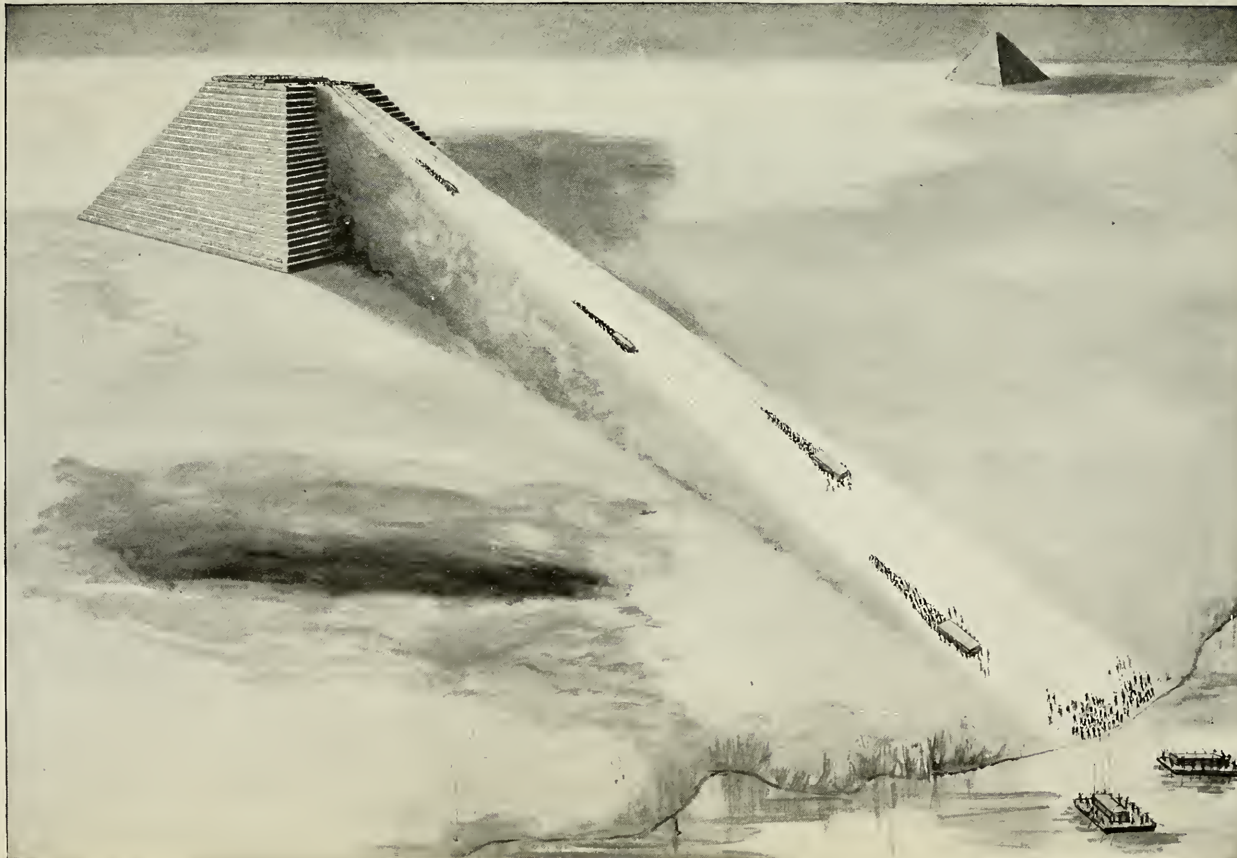
In the great temple of Rameses II is to be found a collossal statue of that king, which equals in dimensions and exceeds in weight any other Egyptian monolith, being 60 feet high and weighing 887 tons 5½ hundredweight. It was made from a single block of red granite brought from the quarries at Assouan, 135 miles distant, by the River Nile.

At Baalbec, Syria, are to be found the ruins of three temples, one of which has been given the name of Trilithon, "Three-stone temple," from the extraordinary proportions of three of the stone blocks found in it, each being over 63 feet in length, 13 feet in height, and proportionately thick. These stones now rest in a wall over 20 feet above the present surface of the ground.

In the solution of the problem of putting similar huge blocks in place at the present day the utilization of inclined planes of earth in the manner just described might well be considered by the modern engineer before adopting a more complex method. In fact, since the various details of this method of construction have suggested themselves, the writer has examined photographs of many ancient structures and has yet to find one that could not have been constructed to a great extent according to the practices just described. Until the principles of the true arch were understood it was less difficult to move and erect long blocks of stone by these primitive methods than to place smaller units



ANCIENT METHODS OF MOVING HEAVY BODIES.



A POSSIBLE METHOD OF INCLINED PLANES BY WHICH THE PYRAMIDS MAY HAVE BEEN BUILT.

over the openings of structures designed in accordance with the types of ancient architecture, in which the arch, with a keystone, was lacking.

Especially was this true in an era when the value of time was not considered, and slaves were to be obtained by thousands, at small cost, to toil and sweat to gratify the ambition and perpetuate the fame of kings.

Happily for our race and time, the crack of the Egyptian slave master's whip and the weird cries in cadence of the battalions of swarthy laborers, while tugging in unison to draw or hoist the monolith, has given place to the puffing engine and the rumble of revolving wheels; but, mayhap, in the years to come, the engineering methods in vogue at the end of this eventful century will seem almost as crude to those who will practice in the new fields of applied science on the borders of which we seem to stand as these primitive methods of the ancients now appear to us. Whether the anticipations for the future shall be realized or not, and proud as we may be of the advances made by discovery and invention in our age, we must not forget that the patient perseverance of the engineers of antiquity, who, by brawn and muscle, and unaided by mechanism, built wiser than they knew, have been rewarded by the preservation of an indelible record of their achievements in the material remains of their edifices that have withstood the ravages of centuries. Will fate so favor the engineer of the nineteenth century, versed in the laws of modern science, and skilled in the practice of the mechanic arts?

Postscript.—Since this paper was published in Cassier's Magazine, there appeared in L'Illustration, Paris, for the first time, an illustrated account of the restoration in 1895–1898 of the Temple of Karnak, the original construction of which was begun by Usertsen I in the twenty-fifth century B. C., being added to by Thothmes III, 1600 B. C., and again by Rameses III, 1200 B. C.

In the work connected with this valuable archæological undertaking, a Frenchman, M. M. G. Legrain, under whose direction the restoration was carried on, employed at one time over 700 Fellahs. The methods adopted to replace the huge carved blocks of stone are thus described in L'Illustration, January, 1899:

> By means of filling in and an inclined plane M. Legrain succeeded in lowering, piece by piece, its architraves of a weight of 57,200 pounds, and its capital and its tambours of 22,000 and 9,900 pounds.
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> * * * * * *
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> It is a curious fact that the Fellahs merely began again exactly what their fathers had done in order to crown with success the work to be accomplished. In looking at these inclined planes and at the laborers bent under baskets of earth, we find ourselves carried back several thousand years, since we have seen the same picture sculptured upon the walls of the edifices in commemoration of their construction. There is but one thing wanting in the modern picture, and we have not to regret it, and that is the man with the lash, the taskmaster of the force of laborers of what was, of old, the land of the Pharaohs.

FELLAHS WORKING ON INCLINED PLANE OF EARTH IN THE RESTORATION OF THE TEMPLE OF KARNAK, 1895-1898.

From L'Illustration, January, 1899.

THE PAST PROGRESS AND PRESENT POSITION OF THE ANTHROPOLOGICAL SCIENCES.[1]

By E. W. Brabrook.

I am very sensible of the honor of presiding over this section at a Bristol meeting. Bristol, from its association with the memory of J. C. Prichard, may be regarded as the very birthplace of British anthropology.

In submitting to this section some observations on the past progress and the present position of the anthropological sciences I use the plural term, which is generally adopted by our French colleagues, in order to remind you that anthropology is in fact a group of sciences. There is what in France is called pure anthropology or anthropology proper, but which we prefer to call physical anthropology—the science of the physical characters of man, including anthropometry and craniology, and mainly based upon anatomy and physiology. There is comparative anthropology, which deals with the zoological position of mankind. There is prehistoric archæology, which covers a wide range of inquiry into man's early works, and has to seek the aid of the geologist and the metallurgist. There is psychology, which comprehends the whole operations of his mental faculties. There is linguistics, which traces the history of human language. There is folklore, which investigates man's traditions, customs, and beliefs. There are ethnography, which describes the races of mankind, and ethnology, which differentiates between them, both closely connected with geographical science. There is sociology, which applies the learning accumulated in all the other branches of anthropology to man's relation to his fellows, and requires the cooperation of the statistician and the economist. How can any single person master in its entirety a group of sciences which covers so wide a field, and requires in its students such various faculties and qualifications? Here, if anywhere, we must be content to divide our labors. The grandeur and comprehensiveness of the subject are among its attractions. The old saying, "I am a man,

[1] Opening address by E. W. Brabrook, C. B., F. S. A., president of the section of anthropology. From Report of the British Association for the Advancement of Science, 1898, pp. 999-1010.

and therefore I think nothing human to be foreign to me," expresses the ground upon which the anthropological sciences claim from us a special attention.

I may illustrate what I have said as to the varied endowments of anthropologists by a reference to the names of four distinguished men who have occupied in previous years the place which it falls to my lot to fill to-day—most unworthily, as I can not but acknowledge, when I think of their preeminent qualifications. When the association last met at Bristol, in 1875, anthropology was not a section, but only a department, and it was presided over by Rolleston. There may be some here who recollect the address he then delivered, informed from beginning to end with that happy and playful wit which was characteristic of him; but all will know how great he was in anatomy, what a wide range of classical and other learning he possessed, and how he delighted to bring it to bear on every anthropological subject that was presented to his notice. In 1878 Huxley was the chairman of this department. It is only necessary to mention the name of that illustrious biologist to recall to your memory how much anthropology owes to him. Eight years before he had been president of the association itself, and seven years before that had published his Evidence as to Man's Place in Nature. Brilliant as his successes were in other branches of scientific investigation, I can not but think that anthropology was with him a favorite pursuit. His writings upon that subject possess a wonderful charm of style. In 1883 the chairman was Pengelly, who for many years rendered service to anthropology by his exploration of Kent's Cavern and other caves, and who happily illustrated the close relation that exists between geology and anthropology. His biography, recently published, must have reminded many of us of the amiable qualities which adorned his character. Finally, in 1886, two years after anthropology had become a section, its president was Sir George Campbell, a practical ethnologist, a traveler, an administrator, a legislator, a geographer, who passed through a long career of public life with honor and distinction. All my other predecessors are, I am glad to say, still living, and I make no mention of them. The few names I have cited—selected by the accidental circumstance that they are no longer with us—are sufficient to show what varied gifts and pursuits are combined in the study of anthropology.

There is another side to the question. Great as is the diversity of the anthropological sciences, their unity is still more remarkable. The student of man must study the whole man. No true knowledge of any human group, any more than of a human individual, is obtained by observation of physical characters alone. Modes of thought, language, arts, and history must also be investigated. This simultaneous investigation involves in each case the same logical methods and processes. It will in general be attended with the same results. If it be true that the order of the universe is expressed in continuity and not in cataclysm, we shall find the same slow but sure progress evident in each branch of the inquiry. We shall find that nothing is lost, that no race is absolutely destroyed, that everything that has been still exists in a modified form, and contributes some of its elements to that which is. We shall find that this, which no one doubts in regard to physical matters, is equally true of modes of thought. We may trace these to their germs in the small brain of the palæolithic flint worker; or, if we care to do so, still further back. This principle has, as I understand, been fully accepted in geology and biology, and throughout the domain of physical science—what should hinder its application to anthropology? It supplies a formula of universal validity, and can not but add force and sublimity to our imagination of the wisdom of the Creator. It is little more than has been expressed in the familiar words of Tennyson—

> "Yet I doubt not thro' the ages one increasing purpose runs,
> And the thoughts of men are widen'd with the process of the suns;"

and supports his claim to be "the heir of all the ages, in the foremost files of time."

I propose, in briefly drawing your attention to some recent contributions to our knowledge, to use this as a convenient theory and as pointing out the directions in which further investigations may be rewarded by even fuller light.

Applying it, first of all, to the department of physical anthropology, we are called upon to consider the discovery by Dr. Dubois at Trinil, in Java, of the remains of an animal called by him *Pithecanthropus erectus*, and considered by some authorities to be one of the missing links in the chain of animal existence which terminates in man. In his presidential address to this association last year, Sir John Evans said: "Even the *Pithecanthropus erectus* of Dr. Eugène Dubois from Java meets with some incredulous objectors from both the physiological and the geological sides. From the point of view of the latter the difficulty lies in determining the exact age of what are apparently alluvial beds in the bottom of a river valley." In regard to these objections, it should be remembered that though the skull and femur in question are the only remains resembling humanity discovered in the site, it yielded a vast number of fossil bones of other animals, and that any difficulty in settling the geological age must apply to the whole results of the exploration. The physiological difficulties arise in two points—do the skull and femur belong to the same individual? Are they, or either of them, human, or simian, or intermediate? As to the first, it is true that the two bones were separated by a distance of about 50 feet, but as they were found precisely on the same level, accompanied by no other bones resembling human bones, but by a great number of animal remains, apparently deposited at the same moment, the theory that they belonged to different individuals would only add to the difficulty of the problem. With regard to the skull, a projection of its outline on a diagram comparing it with others of low type belonging to the stone age shows it to be essentially inferior to any of them. With regard to the thigh, you will recollect that at the Liverpool meeting of this section, Dr. Hepburn displayed a remarkable collection of femora from the anatomical museum of Edinburgh University, exhibiting pathological and other conditions similar to those in the femur of Trinil. Though this evidence tends to show that the bone is human, it is not inconsistent with, but on the contrary goes to support, the conclusion that it belongs to an exceedingly low and ancient type of humanity. Whether, therefore, we call the remains *Pithecanthropus erectus* with their discoverer, or *Homo pithecanthropus* with Dr. Manouvrier, or *Homo Javanensis primigenius* with Dr. Houzé, we are in presence of a valuable document in the early evolution of mankind.

One element of special interest in this discovery is that it brings us nearer than we have ever been brought before to the time when man or his predecessor acquired the erect position. I believe that it is acknowledged by all that the femur belonged to an individual who stood upright, and I presume that the capacity of the skull being greater than that of any known anthropoid is consistent with the same inference. The significance of that has been most clearly set forth by my predecessor, Dr. Munro, in his address to this section at Nottingham in 1893. He showed that a direct consequence of the upright position was a complete division of labor as regards the functions of the limbs—the hands being reserved for manipulation and the feet for locomotion; that this necessitated great changes in the general structure of the body, including the pelvis and the spinal column; that the hand became the most complete and effective mechanical organ nature has produced; and that this perfect piece of mechanism, at the extremity of a freely moving arm, gives man a superiority in attack and defense over other animals. Further, he showed that, from the first moment that man recognized the advantage of using a club or a stone in attack or defense, the direct incentive to a higher brain development came into existence. The man who first used a spear tipped with a sharp flint became possessed of an irresistible power. In his expeditions for hunting, fishing, gathering fruit, etc., primitive man's acquaintance with the mechanical powers of nature would be gradually extended; and thus from this vantage point of the possession of a hand, language, thought, reasoning, abstract ideas would gradually be acquired, and the functions of the hand and the brain be developed in a corresponding manner. I do injustice to Dr. Munro's masterly argument by stating it thus crudely and briefly. It amounts to this—once the erect position is obtained, the actions of man being controlled by a progressive brain, everything follows in due course.

The next stage which we are yet able to mark with certainty is the palæolithic, but there must have been a great many intermediate stages. Before man began to make any implements at all, there must have been a stage of more or less length during which he used any stick or stone that came to his hands without attempting to fashion the one or the other. Before he acquired the art of fashioning so elaborate an instrument as the ordinary palæolithic ax or hammer, there must have been other stages in which he would have been content with such an improvement on the natural block of flint as a single fracture would produce, and would proceed to two or three or more fractures by degrees. It must have been long before he could have acquired the eye for symmetry and the sense of design, of adaptation of means to ends, which are expressed in the fashioning of a complete palæolithic implement. It is probable that such rude implements as he would construct in this interval would be in general hardly distinguishable from flints naturally fractured. Hence the uncertainty that attaches to such discoveries of the kind as have hitherto been made public. Prof. McKenny Hughes, who speaks with very high authority, concludes a masterly paper in the Archæological Journal with the statement that he has "never yet seen any evidence which would justify the inference that any implements older than palæolithic have yet been found." The name "palæotalith," which had been suggested for prepalæolithic implements, seems to him unnecessary at present, as there is nothing to which it can be applied; and as it will be long before it can be asserted that we have discovered the very earliest traces of man, he thinks it will probably be long before the word is wanted. An elaborate work on the ruder forms of implement, just published by M. A. Thieullen, of Paris, who has for many years been engaged in collecting these objects, adds materially to our knowledge of the subject.

Another line of argument bearing strongly in the same direction is afforded by the discovery in various places of works of art fabricated by early man. The statuettes from Brassempouy, the sculptures representing animals from the Bruniquel, the well-known figure of the mammoth engraved on a piece of ivory from Périgord, and many other specimens of early art attest a facility that it is not possible to associate with the dawn of human intelligence. M. Salomon Reinach tells an amusing story. A statuette in steatite of a woman, resembling in some respects those of Brassempouy, was discovered in one of the caverns of Mentone, as far back as 1884, but when the discoverer showed it to a personage in the locality, that authority advised him not to let it be seen, lest it should take away from the belief in the antiquity of the caves, it being then thought too artistic to be consistent with early man. The finder acted on this advice, in ignorance of the real interest of the statuette, until April, 1896, when he showed it to M. Reinach and M. Villenoisy, who promptly interviewed the sage adviser in question, and obtained a confirmation of the statement. Some interesting additions to our gallery of prehistoric art have been recently made by M. Emile Rivière and M. Berthoumeyrou, at Cro-Magnon, in the Dordogne. These are a drawing of a bison and another of a human female in profile, which M. Rivière has kindly allowed me to reproduce. Among the other objects found in the same place were some flint implements brought to a fine point, suitable for engraving on bone or horn.

The idea of making in any form a graphic representation of anything seen has never, so far as I know, occurred to any lower animal; and it could hardly have been among the first ideas formed in the gradually developing human brain. When that idea is found carried out with remarkable artistic skill, by means of implements well adapted for the purpose, we may surely assume that the result was not obtained till after a long interval of time, and was approached by gradual steps marked by progress in other faculties, as well as in the artistic faculty.

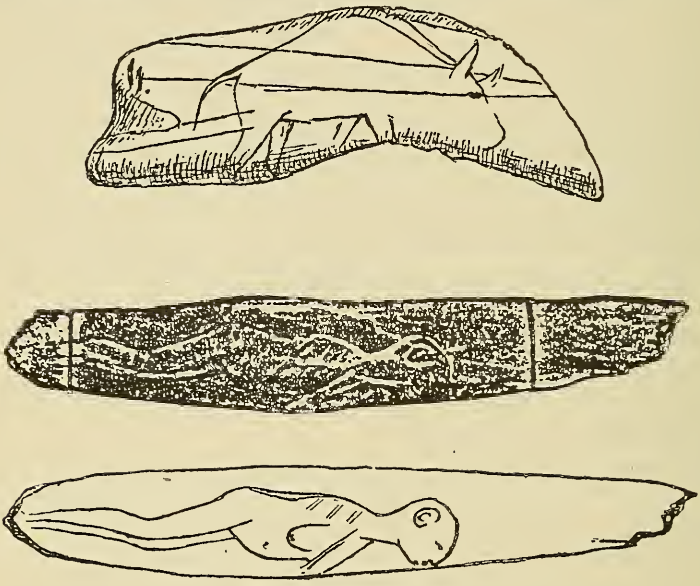


FIG. 1.—Prehistoric art.

It may be that some day all uncertainty on this head will be removed by decisive discoveries.

The interval between the Paleolithic and Neolithic periods rests in the like condition of incertitude. That by some means, and somewhere on the face of the globe, the one period gradually passed into the other we can not but believe. That the transition between them may have involved innumerable degrees is also highly probable. Where and when and how each step was taken we do not know at present, and possibly never shall know. The problem is not satisfactorily solved by the production of paleolithic implements resembling neolithic forms, or neolithic implements resembling paleolithic forms, inasmuch as between the one period and the other an interval of time involving geological and other changes has to be accounted for.

In this respect, also, our best authorities are the most cautious and conservative. In the excellent address which Prof. Boyd Dawkins delivered to the Royal Archæological Institute at the Dorchester meeting last year, on the present phase of prehistoric archæology, he contrasted the few primitive arts, such as sewing, and the manufacture of personal ornaments and rude implements of the chase, possessed by the paleolithic hunters—apart from their great proficiency in the delineation of animals—with the variety of arts, such as husbandry, gardening, spinning, weaving, carpentry, boat building, mining, and pottery making, possessed by the neolithic herdsmen, and held that between the two there is a great gulf fixed. Somewhere the gulf must be bridged over. Prof. Boyd Dawkins says that the bridge is not to be found in the caverns of the south of France. It is difficult to meet his argument that the presence of grains of barley and stones of the cultivated plum at Mas d'Azil are evidences of neolithic civilization. His objections to other discoveries are not so strong as this, but are strong enough to make us pause. The tall, long-headed people whose remains were found at Cro-Magnon, he holds to be early neolithic and not paleolithic, to stand on the near side and not on the far side of the great gulf.

These considerations lend importance to the discoveries which have been laid before this association at previous meetings by Mr. Seton-Kerr, and which have also been commented upon by Prof. Flinders Petrie and Sir John Evans. If we are compelled to admit a breach of continuity in Europe, is it in Africa that we shall find the missing links? That is another of the great problems yet unsolved. The evidence we want relates to events which took place at so great a distance of time that we may well wait patiently for it, assured that somewhere or other these missing links in the chain of continuity must have existed and probably are still to be found.

The next stage, which comprises the interval between the neolithic and the historic periods, was so ably dealt with by Mr. Arthur J. Evans in his address to this section at the Liverpool meeting that it does not call for any observations from me. Two committees appointed by the association in connection with this section touch upon this interval—the committee for investigating the lake dwellings at Glastonbury, and the committee for cooperating with the explorers of Silchester in their well-conducted and fruitful investigation of the influence of Roman civilization on a poor provincial population. I pass on to consider the very great progress that has been made of late years in some of the branches of anthropology other than physical and prehistoric, and especially in that of folklore. I do this the more readily because I do not recollect that folklore has ever before been prominently referred to in an address to this section. It is beginning to assert itself here, and will in time acquire the conspicuous position to which it is becoming entitled, for the British Association is sensitive to every scientific movement and responds readily to the demands of a novel investigation. Already, for three or four years, a day has been given at our meetings to folklore papers, and at the Liverpool meeting an exceeding philosophic, and at the same time practical, paper was read by Mr. Gomme, and is printed in extenso in the proceedings as an appendix to the report of the ethnographic survey committee. The term "folklore" itself is not without a certain charm. It is refreshing to find a science described by two English syllables instead of by some compound Greek word. The late Mr. W. J. Thoms had a happy inspiration when he invented the name. It is just twenty years since the Folklore Society was established under his direction. It has accumulated a vast amount of material and published a considerable literature. It is now rightly passing from the stage of collection to that of systematization, and the works of Mr. J. G. Frazer, Mr. E. Sidney Hartland, and others are pointing the way toward researches of the most absorbing interest and the greatest practical importance.

A generalization for which we are fast accumulating material in folklore is that of the tendency of mankind to develop the like fancies and ideas at the like stage of intellectual infancy. This is akin to the generalization that the stages of the life of an individual man present a marked analogy to the corresponding stages in the history of mankind at large, and to the generalization that existing savage races present in their intellectual development a marked analogy to the condition of the earlier races of mankind. The fancies and ideas of the child resemble closely the fancies and ideas of the savage and the fancies and ideas of primitive man.

An extensive study of children's games, which had been entered into and pursued by Mrs. Gomme, has been rewarded by the discovery of many facts bearing upon these views. A great number of these games consist of dramatic representations of marriage by capture and marriage by purchase—the idea of exogamy is distinctly embodied in them. You will see a body of children separate themselves into two hostile tribes, establish a boundary line between them, demand the one from the other a selected maiden, and then engage in conflict to determine whether the aggressors can carry her across the boundary or the defenders retain her within it.

There can be little doubt that these games go back to a high antiquity, and there is much probability that they are founded upon customs actually existing or just passing away at the time they were first played. Games of this kind pass down with little change from age to age. Each successive generation of childhood is short. The child who this year is a novice in a game becomes next year a proficient and the year after an expert, capable of teaching others, and proud of the ability to do so. Even the adult recollects the games of childhood and watches over the purity of the tradition. The child is ever a strong conservative.

Upon the same principle, next to children's games, children's stories claim our attention. Miss Roalfe Cox has collected, abstracted, and tabulated not fewer then 345 variants of Cinderella, Catskin, and Cap o' Rushes. These come from all four quarters of the globe, and some of them are recorded as early as the middle of the sixteenth century. These elaborate stories are still being handed down from generation to generation of children, as they have been for countless generations in the past. Full of detail as they are, they may be reduced to a few primitive ideas. If we view them in their wealth of detail we shall deem it impossible that they could have been disseminated over the world as they are otherwise than by actual contact of the several peoples with each other. If we view them in their simplicity of idea we shall be more disposed to think that the mind of man naturally produces the same result in the like circumstances, and that it is not necessary to postulate any communication between the peoples to account for the identity. It does not surprise us that the same complicated physical operations should be performed by far distant peoples without any communication with each other. Why should it be more surprising that mental operations not nearly so complex should be produced in the same order by different peoples without any such communication? Where communication is proved or probable it may be accepted as a sufficient explanation; where it is not provable there is no need that we should assume its existence.

The simple ideas which are traceable in so many places and so far back are largely in relation with that branch of mythology which personifies the operations of nature. Far be it from me to attempt to define the particular phase of it which is embodied in the figure of Cinderella as she sits among the ashes by the hearth or to join in the chase after the solar myth in popular tradition. The form of legend which represents some of the forces of nature under the image of a real or fictitious hero capable of working wonders appears to be widely distributed. Of such, I take it, are the traditions relating to Glooscap, which the late Dr. S. T. Rand collected in the course of his forty years' labors as a missionary among the Micmac Indians of Nova Scotia, where, Mr. Webster says, Glooscap formerly resided. The Indians suppose that he is still in existence, although they do not know exactly where. He looked and lived like other men; ate, drank, smoked, slept, and danced along with them, but never died, never was sick, never grew old. Cape Blomidon was his home, the Basin of Minas his beaver pond. He had everything on a large scale. At Cape Split he cut open the beaver dam, as the Indian name of the cape implies, and to this we owe it that ships can pass there. Spencers Island was his kettle. His dogs, when he went away, were transformed into two rocks close by. When he returns he will restore them to life. He could do anything and everything. The elements were entirely under his control. You do not often meet with a mischievous exercise of his power. It is a curious part of the tradition, possibly a late addition to it, that it was the encroachments and treachery of the whites which drove him away.

The early inhabitants of the island of Tahiti appear to have had a whole pantheon of gods and heroes representing the various operations of nature. Even the Papuans have a legend in which the morning star is personified acting as a thief. But it is needless to multiply instances. Lord Bacon, who says "The earliest antiquity lies buried in silence and oblivion. * * * This silence was succeeded by poetical fables, and these at length by the writings we now enjoy, so that the concealed and secret learning of the ancients seems separated from the history and knowledge of the following ages by a veil or partition wall of fables interposing between the things that are lost and those that remain," has shown in his Wisdom of the Ancients that classical mythology was in truth a vast system of nature worship, and in so doing has done more than even he knew, for he has affiliated it to those ideas which have been so commonly formed among rude and primitive peoples. It is true, he says, fables in general are composed of ductile matter, that may be drawn into great variety by a witty talent or an inventive genius and be delivered of plausible meanings which they never contained. But the argument of most weight with him, he continues, "is that many of these fables by no means appear to have been invented by the persons who relate and divulge them, whether Homer, Hesiod, or others; but whoever attentively considers the thing will find that these fables are delivered down and related by those writers not as matters then first invented and proposed, but as things received and embraced in earlier ages. The relators drew from the common stock of ancient tradition and varied but in point of embellishment, which is their own. This principally raises my esteem of these fables, which I receive not as the product of the age or invention of the poets, but as sacred relics, gentle whispers, and the breath of better times, that from the traditions of more ancient nations came at length into the flutes and trumpets of the Greeks."

Except that he supposes them to be a relic of better times, the poet's dream of a golden age no doubt still ringing in his ears, Bacon had in this, as in many other matters, a clear insight into the meaning of things.

Another idea that appears among very early and primitive peoples and has had in all time a powerful influence on mankind is that of a separable spirit. The aborigines of northwest central Queensland, who have lately been studied to such excellent purpose by Dr. Walter Roth, the brother of a much-esteemed past officer of this section, are in many respects low in the scale of humanity, yet they possess this idea. They believe that the ghost or shade or spirit of some one departed can so initiate an individual into the mysteries of the craft of doctor or medicine man as to enable him, by the use of a death-bone apparatus, to produce sickness and death in another. This apparatus is supposed to extract blood from the victim against whom it is pointed without actual contact and to insert in him some foreign substance. They will not go alone to the grave of a relative for fear of seeing his ghost. It appears that they have the fancy that Europeans are ghosts. The Tasmanians also, as Mr. Ling Roth himself tells us, had the same fancy as to the Europeans and believed that the dead could act upon the living. The Pawnee Indians, we are assured by Mr. Grinnell, believe that the spirits of the dead live after their bodies are dust. They imagine that the little whirlwinds often seen in summer are ghosts. The Blackfeet think the shadow of a person is his soul and that while the souls of the good are allowed to go to the sand hills, those of the bad remain as ghosts near the place where they died. The Shillooks of Central Africa are said to believe that the ghostly specters of the dead are always invisibly present with the living and accompany them wherever they go. The aborigines of Samoa believed in a land of ghosts, to which the spirits of the deceased were carried immediately after death. The religious system of the Amazulu, as described by Bishop Callaway, rests largely on the foundation of belief in the continued activity of the disembodied spirits of deceased ancestors.

Mr. Bryce, in his "Impressions of South Africa," says that at Lezapi, in Mashonaland, are three huts, one of which is roofed and is the grave of a famous chief whose official name was Makoni. "On the grave there stands a large earthenware pot, which used to be regularly filled with native beer, when, once a year, about the anniversary of his death, his sons and other descendants came to venerate and propitiate his ghost. Five years ago, when the white men came into the country, the ceremony was disused, and the poor ghost is now left without honor and nutriment. The pot is broken, and another pot, which stood in an adjoining hut and was used by the worshipers, has disappeared. The place, however, retains its awesome character, and a native boy who was with us would not enter it. The sight brought vividly to mind the similar spirit worship which went on among the Romans, and which goes on to-day in China; but I could not ascertain for how many generations back an ancestral ghost receives these attentions—a point which has remained obscure in the case of Roman ghosts also."

The aborigines of New Britain are said to believe that the ghosts of their deceased ancestors exercise a paramount influence on human affairs, for good or for evil. They have the poetical idea that the stars are lamps held out by the ghosts to light the path of those who are to follow in their footsteps. On the other hand, they think these ancestral ghosts are most malicious during full moon. Not to multiply instances, we may say with Mr. Staniland Wake, it is much to be doubted whether there is any race of uncivilized men who are not firm believers in the existence of spirits or ghosts. If this is so, and the idea of a separable spirit, capable of feeling and of action apart from the body, is found to be practically universal among mankind, and to have been excogitated by some of the least advanced among peoples, and if we observe how large a share that idea has in forming the dogmas of the more specialized religions of the present day, we shall not see anything inherently unreasonable in the generalization that the group of theories and practices which constitute the great province of man's emotions and mental operations expressed in the term "religion" has passed through the same stages and produced itself in the same way from these early rude beginnings of the religious sentiment as every other mental exertion. We shall see in religion as real a part of man's organization as any physical member or mental faculty. We shall have no reason to think that it is an exception to any general law of progress and of continuity which is found to prevail in any other part of man's nature.

The same inference may be drawn from many other considerations. Take, for instance, the belief in witchcraft, which is so characteristic of uncivilized man that it is hardly necessary to cite examples of it. The Rev. Mr. Coillard, a distinguished missionary of the Evangelical Society of Paris, in a delightful record, which has just been published, of his twenty years' labors as a missionary pioneer among the Banyai, and Barotzi of the Upper Zambesi, "on the threshold of Central Africa," says: "In the prison of the Barotzi, toiling at earthworks, is a woman—young, bright, and intelligent. She told me her story. A man of remarkably gentle character had married her. The king's sister, Katoka, having got rid of one of her husbands, cast her eyes on this man and took him. He had to forsake his young wife—quite an easy matter. Unfortunately, a little later on, a dead mouse was found in the princess' house. There was a great commotion, and the cry of witchcraft was raised. The bones did not fail to designate the young woman, and she was made a convict. A few years ago she would have been burned alive. Ah, my friends, paganism is an odius and a cruel thing." Ah, Mr. Coillard, is it many years ago that she would have been burnt alive or drowned in Christian England or Christian America? Surely the odiousness and the cruelty are not special to paganism any more than to Christianity. The one and the other are due to ignorance and superstition, and these are more hateful in a Matthew Hale or a Patrick Henry than in a Barotzi princess in the proportion that they ought to have been more enlightened and intelligent than she. It is only one hundred and twenty-two years since John Wesley wrote: "I can not give up to all the Deists in Great Britain the existence of witchcraft;" and I believe that to this day the Order of Exorcists is a recognized order in the Catholic Church.

The same line of argument—which, of course, I am only indicating here—might be pursued, I am persuaded, in numberless other directions. Mr. Frazer, in his work on the Golden Bough, has most learnedly applied it to a remarkable group of beliefs and observances. Mr. Hartland has followed up that research with a singularly luminous study of several other groups of ideas in the three volumes of his "Legend of

Perseus." More recently, Mr. Andrew Lang has sought to show that the idea of a Supreme Being occurs at an earlier stage in the development of savage thought than we had hitherto supposed. Striking as these various collocations of facts and the conclusions drawn from them may appear, I am convinced there is much more for the folklorist to do in the same directions.

The principle that underlies it all seems to be this: Man can destroy nothing, man can create nothing, man can not of his own mere volition even permanently modify anything. A higher power restrains his operations, and often reverses his work. You think you have exterminated a race; you have put to the sword every male you can find, and you have starved and poisoned all the survivors of the community. In the meanwhile, their blood has been mingled with yours, and for generations to come your bones and those of your descendants will preserve a record of that lost race. You think you have exterminated a religion; you have burned to death all of its teachers you can find, and converted forcibly or by persuasion the rest of the community. But you can not control men's thoughts, and the old beliefs and habits will spring up again and again, and insensibly modify your own religion, pure as you may suppose it to be.

Huxley, in his address to the department of anthropology twenty years ago, said, with the force and candor that were characteristic of him: "Anthropology has nothing to do with the truth or falsehood of religion—it holds itself absolutely and entirely aloof from such questions—but the natural history of religion and the origin and the growth of the religions entertained by the different kinds of the human race are within its proper and legitimate province." I do not presume to question that as an absolutely accurate definition of the position—it could not be otherwise; but if there be any here to whom what I have been suggesting is in any sense novel or startling, I should be glad to be allowed to say one word of reassurance to them. When my friend Mr. Clodd shocked some of the members of the Folklore Society by his frank statement of conclusions at which he had arrived, following the paths I have indicated, it was said we must fall back on the evidences of Christianity. What more cogent evidence of Christianity can you have than its existence? It stands to-day as the religion which, in most civilized countries, represents that which has been found by the operation of natural laws to be best suited for the present circumstances of mankind. You are a Christian because you can not help it. Turn Mahometan to-morrow, will you stop the spread of Christianity? Your individual renunciation of Christianity will be but a ripple on a wave. Civilized mankind holds to Christianity, and can not but do so till it can find something better. This, it seems to me, is a stronger evidence of Christianity than any of the loose-jointed arguments I find in evidential literature.

Upon this thorny subject I will say no more. I would not have said so much, but that I wish to show that these considerations are not inconsistent with the respect I entertain, and desire now as always to express for those feelings and sentiments which are esteemed to be precious by the great majority of mankind, which solace them under the adversities of life and nerve them for the approach of death, and which stimulate them to works of self-sacrifice and of charity that have conferred untold blessings on humanity. I reverence the divine founder of Christianity all the more when I think of Him as one who so well "knew what was in man" as to build upon ideas and yearnings that had grown in man's mind from the earliest infancy of the race.

To return. If continuity be the key that unlocks the receptacle where lie the secrets of man's history—physical, industrial, mental, and moral; if in each of these respects the like processes are going on—it follows, as I have already said, that the only satisfactory study of man is a study of the whole man. It is for this reason that I ask you to take especial interest in the proceedings of one of the committees of this section, which has adopted such a comprehensive study as the guiding principle of its work—I mean the ethnographical survey committee. I have so often addressed this section and the Conference of Corresponding Societies on the matter, since the committee was first appointed at the Edinburgh meeting, on the suggestion of my friend, Professor Haddon, that I can hardly now refer to it without repeating what has been already said or forestalling what will be said when its report is presented to you, but its programme so fully realizes that which has been in my mind in all that I have endeavored to say that I must make one more effort to enlist your active interest in its work.

The scheme of the committee includes the simultaneous recording in various districts of the physical characters, by measurement and by photography, the current traditions and beliefs, the peculiarities of dialect, the monuments and other remains of ancient culture, and the external history of the people. The places in the United Kingdom where this can be done with advantage are such only as have remained unaffected by the great movements of population that have occurred, especially of late years. It might have been thought that such places would be very few, but the preliminary inquiries of the committee resulted in the formation of a list of between 300 and 400. So far, therefore, as the testimony of the very competent persons whose advice was sought by them is to be relied on, it is evident that there is ample scope for their work. At the same time, the process of migration from country to town is going on so rapidly that every year diminishes the number of such places. One thinks with regret how much easier the work would have been one or two or three generations ago; but that consideration should only induce us to put it off no longer. The work done by the lamented Dr. Walter Gregor for this committee in Dumfriesshire and other parts of Scotland is an excellent type of the way in which such work should be done. His collections of physical measurements and of folklore have been published in the fourth and fifth reports of the committee. There can be no doubt that few men possess the faculty he had of drawing forth the confidence of the villagers and getting them to tell him their superstitions and their old customs. He succeeded in recording from their lips not fewer than 733 items of folklore. They not merely form exceedingly pleasant reading, such as is perhaps not often met with in a British Association report, but they also will be found to throw considerable light on the views which I have ventured to lay before you. It is much to be wished that others who have the like faculty, if even in a lesser degree, could be induced to take up similar work in other districts, now that Dr. Gregor has so well shown the way in which it ought to be done.

The work done by the committee for the ethnographical survey of Canada; the completion of the ethnographical survey of the North-western tribes, which has been ably conducted for many years; and the progress made in the ethnographical survey of India will also be brought under your notice, the latter in a paper by Mr. Crooke, who has worked with Mr. Risley upon it.

Another movement, which was originated by this section at the Liverpool meeting, and was referred to in the report of the council of the association last year, has made some progress since that report was presented. Upon the recommendation of this section, the general committee passed the following resolution and referred it to the council for consideration and action:

"That it is of urgent importance to press upon the Government the necessity of establishing a bureau of ethnology for Greater Britain, which, by collecting information with regard to the native races within and on the borders of the Empire, will prove of immense value to science and to the Government itself."

The council appointed a committee, consisting of the president and general officers, with Sir John Evans, Sir John Lubbock, Professor Tylor, and your esteemed vice-president, Mr. Read, the mover of the resolution. Their report is printed at length in last year's report of council, and shows clearly how useful and how easily practicable the establishment of such a bureau would be. The council resolved that the trustees of the British Museum be requested to consider whether they could allow the proposed bureau to be established in connection with the museum. I understand that those trustees have returned a favorable answer; and I can not doubt that the joint representations which they and this association will make to Her Majesty's Government will result in the adoption of a scheme calculated to realize all the advantages which we in this section have so long looked for from it. In the secretary of state for the colonies and the chancellor of the exchequer we have statesmen who can not fail to appreciate the benefits the community must derive from acquiring accurate and scientific knowledge of the multifarious races which compose the Empire.

Those of us who visited the United States last year had the opportunity of observing the excellent work which is done by the Bureau of Ethnology at Washington, and those who stayed at home are probably familiar with the valuable publications of that department. An act of Congress twenty years ago appropriated £4,000 a year to the Smithsonian Institution for the continuance of researches in North American anthropology. The control of the Bureau was intrusted to the able hands of Major Powell, who gathered round him a band of skilled workers, many of whom had been previously engaged on ethnographic research under the direction of the Geographical and Geological Survey of the Rocky Mountain region. In field work and in office work, to use Major Powell's convenient distinction, ample return has ever since been rendered to the United States Government for the money thus appropriated, which has since been increased to £8,000 a year. Our own bureau of ethnology would have a wider sphere of operations, and be concerned with a greater number of races. It would tend to remove from us the reproach that has in too many cases not been without foundation—that we have been content to govern races by the strong hand without caring to understand them, and have thus been the cause of injustice and oppression from ignorance rather than from malevolence. If that were only a record of the past, we might be content with mere unavailing regret; but the colonial empire is still expanding, and we and our competitors in that field are still absorbing new districts—a practice which will probably continue as long as any spot of ground remains on the face of the globe occupied by an uncivilized race.

Would it not be worth while at this juncture to extend to the peoples of Africa, for instance, the principles and methods of the Ethnographic Survey—to study thoroughly all their physical characters, and at the same time to get an insight into the working of their minds, the sentiments and ideas that affect them most closely, their convictions of right and wrong, their systems of law, the traditions of the past that they cherish, and the rude accomplishments they possess? If for such a service investigators like Dr. Roth, who began his researches in Queensland by so close a study of the languages and dialects of the people that he thoroughly won their confidence, could be found, the public would soon learn the practical value of anthropological research. If the considerations which I have endeavored to urge upon you should lead not only the scientific student but the community at large to look upon that which is strange in the habits and ways of thinking of uncivilized peoples as representing with more or less accuracy a stage in that long continuity of mental progress without which civilized peoples would not be what and where they are, it could not but favorably affect the principles and practice of colonization. Tout comprendre c'est tout pardonner. The more intimate our acquaintance with the races we have to deal with and to subjugate, the more we shall find what it means to stand with them on the same platform of common humanity. If the object of government be, as it ought to be, the good of the governed, it is for the governing race to fit itself for the task by laying to heart the lessons and adopting the processes of practical anthropology.

THE ORIGIN OF AFRICAN CIVILIZATIONS.[1]

By L. Frobenius

The day of great exploring expeditions in Africa is over. Bold lines, only occasionally broken up into dots, and great and little bluish-green spots of curious outline fill the white spaces which stare the student in the eyes in the times of scientific truth, and in the times of more vivid fancy were adorned with the figures of grotesque animals and with neat inscriptions like *Caput Nili* and *Montes Lunæ*. In its main features, the picture is unrolled before our eyes. One is tempted to believe that the old Roman question about Africa not only has become too trivial to be put, but has lost its justification. That, however, is not quite true. What bold investigators, great pioneers, still find to tell us of civilizations nearer home, proves more and more clearly that we are ignorant of hoary Africa. Somewhat of its present, perhaps, we know, but of its past little.

We ethnologists have fared particularly ill. Far from bringing us answers to our questions, the travelers have increased our enigmas by many an addition so peculiar that astonishment has scarcely yet made room for investigation. For the pictures of the inhabitants and the specimens of their civilization are indeed questions. Open an illustrated geography and compare the "Type of the African Negro," the bluish-black fellow of the protuberant lips, the flattened nose, the stupid expression, and the short curly hair, with the tall bronze figures from Dark Africa, with which we have of late become familiar, their almost fine-cut features, slightly arched nose, long hair, etc., and you have an example of the problems pressing for solution. In other respects, too, the genuine African of the interior bears no resemblance to the accepted negro type as it figures on drug and cigar store signs, wearing a shabby stovepipe hat, plaid trousers, and a varicolored coat. A stroll through the corridors of the Berlin Museum of Ethnology teaches that the real African need by no means resort to the rags and tatters of bygone European splendor. He has precious ornaments of his own, of ivory and plumes, fine plaited willow ware, weapons of superior workmanship.

[1] Translated from Sonder-Abdruck aus der Zeitschr. der Gesellsch., f. Erdk. zu Berlin, Bd. XXXIII, 1898.

Nothing more beautiful, for instance, can be imagined than an iron club carefully wound round with strips of metal, the handle covered with snake skin.

Wolf, Wissmann, Pogge in the south, Schweinfurth and Junker in the north, justly demanded "What sort of civilization is this? Whence does it come?"

For years I have been occupied with the problems of the evolution of the African nations; that is, the history of African civilization, and long the origin of the peculiar civilization of the Congo Basin haunted me as the most difficult of all the questions involved. Some time after the solution had been found a first essay was published in Petermann's Mitteilungen (1897, Parts X and XI), where, I hope, by the way, that its continuation will shortly be published. In this article various aspects of African culture were subjected to an examination as to their constituent elements, the composition of each, its prevalence, and its origin. The areas of distribution of elements of the same origin were represented on charts, and it was made to appear that elements of the same origin were of equal range. With regard to the affinity of the elements of African civilization, the new and astonishing fact of their Malayo-Negrito relationship was established. Once only it had been referred to before, by Friedrich Ratzel in his well-known work on African bows, where, however, the consequences following from it were not traced.

The article was misunderstood in various ways. The daily press took hold of the matter, and credited me with the opinion that Malays are living in West Africa. The fact that the Malayo-Negritos were left undefined was taken amiss, etc. It therefore seems advisable to review the whole statement briefly. It must be borne in mind that the article in Petermann's Mitteilungen was but the beginning of a more extended treatise, the continuation of which will appear shortly.

The question concerning the origin of the civilization of the interior of Africa can not be solved without reference to the composition of African civilization in general, and this in turn requires consideration of the question: How can culture affinities be determined?

1. The proof of culture affinity[1] depends upon our conception of civilization. Consideration of our own culture and that of others teaches that the history of peoples and the history of civilizations fall short of identity only in the measure in which forms of civilization, more than peoples, are the creatures of their surroundings and of the home soil. Though Roman culture was derived from Greek, the culture of North America from that of England, the Renaissance in Germany, in the Netherlands, and in France, from the Renaissance in Italy, yet they are not the same. On the soil which produced the classic culture of

[1]The whole of this is a sketch-like reproduction of the detailed investigations contained in the work: Der Ursprung der Kultur, Vol. I; Der Ursprung der afrikanischen Kulturen, which is to be published before the end of the year by Gebrüder Bornträger, Berlin.

Rome, the Renaissance put forth her most exquisite blossoms, yet the two differ in kind. The variation between the mothers is patent. Besides, every form of civilization passes through a genetic period, a period of maturity, during which it may propagate itself—how widely Rome scattered her seeds!—and a period of decay. Civilization, then, resembles an organic being in its development—it is born, it perishes, it can propagate itself. More particularly it resembles a plant—it takes root in the soil, and when its seeds fall into other land new varieties sprout up.

Now, the cartographic presentation in Petermann's Mitteilungen taught a fact of primary importance, that certain culture elements appear together and are equally distributed. Thus, in spite of transitions, mixtures, irregularity of occurrence near the boundary lines, they are made to assume corporeal form by means of a certain unity of distribution. We have the proof that it is possible, if only in roughest outline, to trace geographic position and extent.

Again, the cartographic method of ethnography demonstrated that, in spite of great variability, the marks of origin are indelibly impressed upon the framework of these forms or creatures of civilization. In other words, it has been ascertained that ethnographic objects illustrative of phases of culture may be examined with a view to fixing their descent, as we examine the limbs and organs of a living being.

The gain is great which thus accrues to the history of civilization and of mankind. The astonishing fact of the Malayo-Negrito origin of West African culture proves how far from their source prehistoric forms of civilization wandered, and warns us, especially in the case of complicated products, not to talk too much of local discovery of natural laws, of independent invention and origin. It is becoming clearer and clearer that the manifold ramifications of human culture are but the crown of a single race, a fact which was repeatedly stated by Ratzel, but which could scarcely have been established with certainty until now.

The material awaiting investigation has itself indicated the way to the possible solution of the problems. We have alluded to the characteristics of culture forms which make them appear similar to animals. Now, then, as the affinities and the descent of the latter have been recognized, so the affinities and the descent of culture forms are demonstrable.

Scientists have succeeded in making out the genealogical tree, as it were, of animals by following up the developments of the parts of the organism, the changes, under various conditions, in the organs, the modifications in certain bones, etc. I maintain that the same is possible in the study of culture forms. Shields, bows, spears, and huts recur, to be sure, on every continent, in all ethnological groups, in astonishingly similar forms; but closer attention reveals this similarity to be only apparent. They are separated from one another by vital differences, reaching back often to their very origin.

Our first aim, then, should be to become acquainted with the development of the products of a given form of civilization, and it is attained by means of culture-anatomy, as illustrated in Petermann's Mitteilungen.

This initial step in the work of investigating is bound to lead to the desired goal, if we succeed in presenting the peculiarity of the material on the one side and the form and nature of the object on the other, so as to make it appear that the object grew out of the material as a necessary consequence. Frequently the question of origin is solved with the determination of the province in which the material is indigenous. Other forms of civilization adopt the object and fashion it of other material. The student may thus have to travel along the same road again and again.

After the elements of a given form of civilization have been defined, culture physiology follows as a second part of the investigation. It can easily be demonstrated that differences in geographic position condition differences in the phenomena of civilization. Not only does an island race differ from the races of the mainland in its means of support, but it is peculiar as to social conditions, weapons, etc. The problem is complicated by the fact that local material gives rise to a series of utensils and ornaments whose existence is due solely to the material, and which are replaced by other products when the culture in question is transplanted. The forms remain, the material changes, and again the investigator must retrace the path to the point of departure.

In the following it will be my endeavor to make this outline more intelligible by means of illustrations.

2. Our investigation of culture-anatomy may begin with African drum forms. By far the larger part of African drums consist of a log scooped out, one or both ends covered with hide. We need not enter into details here, and I do no more than state the fact that the Indonesian method of bracing drums reappears on the West African coast. Besides these commonest drum forms, others occur made entirely of a log, hewn round or with angles; in the latter case usually wedge-shaped, the broad surface resting on the ground. The logs are hollowed out within through a cleft, made always on the broad side. Often the cleft is enlarged at its ends, the enlargement forming a round aperture in the drums of the Congo, an angle in those of the Cameroons. The famous signaling or telegraph drums of the Cameroons belong to this class. The drums covered with hide are found throughout the whole of Africa, with the exception of its southernmost part, but the wooden drums occur only in the Congo Basin and in Upper and Lower Guinea. The hide-covered drums are a development of the famous millet mortar, which points to East India. The civilization of the Mediterranean shores has similar drums made of clay, and related to those found in Persia and in prehistoric tombs of Germany. Now, the wooden drums belong to the Malayo-Negrito elements of African culture. They

recur in Melanesia and frequently in Polynesia. Their home obviously must be the same as that of the lofty bamboo cane, for these drums are developed from the bamboo.

The stringed instruments of the Africans follow the drums most naturally. The Africans possess a greater variety of these instruments than any other peoples living in a state of nature. Every foreign form adopted by them brings forth an enormous progeny. We shall mention only the more important considerations, the most important, first of all, that despite their love of music the Africans invented no stringed instrument. Their wealth of forms arises from modifications of foreign patterns, derived chiefly from India, West Asia, and the Malay Archipelago; that is, Indo-China or Melanesia. The instrument from West Asia resembles the guitar, and is distinguished by a sounding-board covered with skin, by strings made of sinew, hair, or strips of skin, and by the presence of a peg. It has spread through North Africa from Senegambia to Abyssinia. More than that, penetrating farther than other importations from West Asia, it has reached the lands along the Ogome and the Sande. We note a preponderance of animal material in contrast with the Malayo-Negrito stringed instruments, the original form of which is preserved between the Niger (Ibo) and the Congo (Bateke). It is made of reed, or the stem of the raphia, or bamboo (bamboo palm). Several strips are loosed along its whole length except at the two ends, where they are furthermore secured by rings of rattan (rotang). These rings, together with a board or rod in the middle, interposed between the strips and the reed so as to form a bridge, serve to brace the strips. On the underside of the bridge a sounding-board in the shape of a gourd (calabash) is attached. Numerous as the forms are that have developed from this simple instrument, they are all characterized by vegetable strings, a bridge, a vegetable sounding-board, and mostly by rattan rings. The stringed instrument just described is the direct descendant of the well-known Indonesian bamboo instrument. The area of prevalence of the Malayo-Negrito features pointed out is coextensive with that of the Malayo-Negrito drums.

Ratzel was the first to recognize the bows of the Africans as excellent material for classification. There are three kinds. Through old as well as recent illustrations we are most familiar with the Asiatic weapon, consisting of two limbs, each arched, with a depression in the middle where the limbs meet. It is spread from north to south, approximately as far as the bearers of Islam penetrated and in the Nile territory even beyond their settlement. The second variety is the East Indian weapon, which was obviously developed here at the point of contact between the two chief forms of the bow, that is, the North Asiatic form just mentioned, and the Malayo-Negrito form. The typical Malayo-Negrito form has but a single arch, a bowstring of vegetable fiber, a groove on the inner side, and buttons plaited of rattan or carved out of wood, to hold the bowstring in place at the two ends. It is ornamented with rattan rings. This bow prevails within the domain of West African civilization. The East Indian mongrel type, on the other hand, characterized by the down and inward bending of the bow ends, is found in the north (in the gaps of the territory covered by the Asiatic bow), the east, and the south of the continent. Again we see the Malayo-Negrito implement of the West Africans, with its rattan bowstring, its rattan buttons, and its rattan ornaments, distinguished by vegetable material.

The shields of the Africans reveal three points of departure. The first is the West Asiatic round buckler with a protuberance. It is most frequently made of the skins of the pachydermata. Abyssinian bucklers can with difficulty be distinguished from those of West Africa, even the iron mountings of the two being the same. The smaller Somali shield is pressed. To this class belongs one of the Lango shields, the one with the convex form and of the size of a man's head. On the other side of Africa modifications from the type were made in favor of greater, as on this side in favor of smaller size. The shields of the western Sudan, made of elephant's skin, cover horse and rider. The defensive armor of the Baghirmi, and especially of the Nubians, falls under the same group. The second primary form is represented by the Negrito staff-shield, the kuerr of the Dinka and the kirvi of the Hottentots. These are staffs, sometimes with, but usually without, handholds, used in Africa as parrying weapons. Negrito civilization among the Australasians, as, for instance, in Marsa, etc., furnishes much better specimens of the same. Here the thickening of the staff toward the middle is accompanied by a hollowing out into a handhold. These characteristics recur among the African Negrito forms only in the kuerr of the Dinka. In all others the handhold is replaced by a strip of hide around the hand and the staff. The widening of the strip has led to the form familiarly known under the name of Zulu shields. On the borders of the territory of the round Asiatic bucklers, a mongrel type is found in the Massai shields. The staff in the middle, being the chief defense and serving as the handhold, has been preserved. Hide is replaced by skin, which is kept stretched by means of a pad around the edge. A slight protuberance, probably to increase the space between the hand and the staff, is noticeable. The third place is filled by the reed-covered wooden shield of the Baluba, as Livingstone became acquainted with it near Shinto, Gamietto along the Kazembe, and Wissmann and Pogge to the north of the line connecting these two points. The shield of Bukoba, near Lake Victoria, is essentially the same. That of the Wanyoro, Waganda, Wakavirondo, on the other hand, is of finer workmanship. The well-known Ambatsh shield of the Wakarra lacks the rattan covering, while that of the Kongo and Sande races consists of reed plaiting alone, without the wooden foundation. We can easily understand how this change takes place, that is, how the wooden framework gradually dwindles into nothing more than a protection for the fist. In fact, the reason for the modification can be shown. The wooden framework is absent in the territory of pointed iron missiles. The yielding reed surface does not permit them to enter; they glance off and lose their momentum. Wooden shields with reed covering reappear on the coast of Upper Guinea. We know them also from the Gold Coast, and older accounts mention them in the Liberian region. Related forms are found in New Guinea and the Solomon Islands. Here again Malayo-Negrito affinity is bound up with the vegetable material.

The axes of the Africans are frequently characterized as being of the same form everywhere. Such a statement is not in accordance with fact. The great differences among them become obvious on a comparison of the Dahomey ax with one from Bihe, and, again, with one from East Africa. The helve of the Dahomey ax is bent forward at the upper end, the head being inserted in the deflected portion. This form obviously originated in the hoe. The East African ax is a smooth staff, into which the head is wedged so that a considerable piece of the blade protrudes above. The handle of the South African ax is bent backward, and is sometimes adorned with all sorts of curious scallops and ornaments. Into this projection the tang of the blade is fitted. The blade itself is of extraordinary shape, taking its rise in a little cylinder polished down in front. Several considerations determine my opinion that the last is of Malayo-Negrito origin. In other words, it is derived from a stone, or, rather, a shell ax. The cylindrical form of the head is the one occurring in the Melanesian shell ax, later stone ax. In Oceania the head directly or, by the intervention of the handle, indirectly is laced to the backward bent helve. The lacings are reproduced in the West African ornamentation with its peculiar zigzag lines. The ax forms derived from the hoe are connected with the cultivation of millet—that is, they are of East Indian extraction.

The huts of the Africans show manifold primary forms. Two factors indicate as many zones of influence. Building with clay extends from the north to the Sudan and is suggestive of Egyptian brick buildings and the architecture of Asia Minor, therefore of west Asiatic influence. The Kongo Basin and North Guinea are the region of former pile dwellings, whose last remaining trace is easily discerned even now in the peculiar window doors. This bears witness to Malayo-Negrito affinity. The northern domain, in which clay is used, is gradually enlarging, while the southwestern is more and more suffering contraction. But the affinity of the hut forms goes further; it is fundamental. The West and Central African house is constructed like a house of cards—of six mats made of palm leaves, two forming the roof and four the walls, all tied to one another. The inside space is partitioned off into rooms by mats suspended from above. The Oceanian house is exactly like this, only it is raised on piles. Often, too, the number of outer walls is reduced. On the other hand, the interior division into chambers is the same as in Africa, but occurs more frequently. Pile dwellings are concomitants of a fixed domicile, or, rather, a settled mode of living is a result of limited insular spaces fit for habitation. The nomadic habits of the Africans were destructive of stability. The durable pile dwelling is therefore declining steadily, and the simple portable card house remains as the continental form of the original Malayo-Negrito island hut. H. Frobenius has proved that the round huts show two modes of construction—the one exemplified in the Sudan and along the Nile, the other in the east and south. One of them at least, the northern form, which can be traced back to the tent, is demonstrably of East Indian affinity.

The chairs and neck rests of the Africans exhibit so rich a variety of forms that it is difficult to disentangle the web without illustrations and lengthy descriptions. It may be stated that the South Africans, excluding Hottentots and Bushmen, show transitional forms pointing to Oceania. There are two or four feet. The seat is supported by figures of men and animals, often degenerating into grotesque ornaments. The neck rests, however, attain to full development only along the Zambesi, and finally manifest Malayo-Negrito sense of beauty of form only in the Kongo Basin and in North Guinea. Moreover, in many instances it is questionable whether the object under consideration is a chair or a neck rest. The form with one round foot belongs to the whole of the north.

The costumes of the Africans in one respect point to the soil, to the means of support. Wherever in Africa cattle breeding is carried on, that is to say, in the whole of South and East Africa, and in the Sudan, we find hide and leather clothing, except that in the east and the north of the Sudan leather is replaced by cotton. Cotton is met with also in the southeast and in the southwest, pointing to India as the place of departure. The eastern must be added as the last of the cotton areas. In the west, on the other hand, that is, in the Kongo Basin, the fabric that predominates is made of palm fibers, a phenomenon of Malayo-Negrito origin. Two small enclaves on the east side indicate how the manufacture of these tissues reached Africa. The path of diffusion of a fourth material, that made of bark, is still more evident. There can be no other explanation for the two broad strips of territory on which it occurs, extending from the east coast, the lake and forest region. In patches of territory, here and there, bark fabrics occur in the Sudan too, but they prevail to the exclusion of all others only in the northern and western part of the Kongo Basin. In the southern Sudan they appear by the side of other materials. On the western coast, among the southern Cameroons and along the Volta, bark tissues are still in use, and on the Bissagos Islands they were once common. The Malayo-Negrito affinity of the bark fabrics of Africa with the well-known tapa cloth of the natives of Oceania is favored by the fact that the trees yielding the raw material are planted and tended in great quantities in newly-founded villages.

3. The investigation into culture physiology may proceed from the proposition that all the Malayo-Negrito elements discussed above are distributed essentially over the same area. The solid tract of territory covered by them lies in the Kongo Basin, extending southward to the Zambesi Valley, northward to the lands about the sources of the Shari, and eastward to the East African area of depression. In the northwest the area of Malayo-Negrito elements continues along the Guinea coast into Senegambia, but the limits can no longer be determined with certainty. In the course of the last few centuries Semito-Negritoes from the interior and Europeans from the coast have either brought about complete destruction of native culture, or effected far-reaching changes. Upon the diffusion of culture elements of other affinities we shall expatiate later.

Outside of the unbroken domain of Malayo-Negrito culture, phenomena of the same kind and descent occur in disconnected, widely separated regions all over Southeast and East Africa. On the one hand we are reminded thereby that culture elements other than those of Malayo-Negrito origin are found within the area of distribution claimed for the latter. These non-Malayo-Negrito elements either are found in enclaves of exclusive occupation, pointing to the fact of recent immigration, or they appear in fraternal association with the Malayo-Negrito elements, which in this case have been thoroughly interpenetrated with African elements, and have completely absorbed them. On the other hand, the occurrence of objects of Malayo-Negrito origin outside of their west African central abode indicates the extent of their former distribution, or the path of migration.

In itself the fact of agreement in form between certain or indeed all of the objects in use in West Africa and those of Oceania is not convincing proof of their culture affinity. But likeness of anatomical origin coupled with the outlined area of distribution is evidence not to be gainsaid. Slowly progressing contraction of the area of distribution until it is narrowed down to a border, or strip, in the west, together with isolated remains in the mountains, near the mouths of rivers, or in other out of the way places not readily inundated by waves of national migrations—this is the characteristic of the present zone of Malayo-Negrito civilization in Africa.

And this area of distribution proves not only the path along which Malayo-Negrito civilization traveled, but also that along which other civilizations made their way. By the same side, in all probability, entered from India the use of iron and the cultivation of millet and cotton. The spread of these elements, pressing forward victoriously from the East, is an eloquent witness, when we remember that the East Indian bellows are not found among the southwestern tribes. The descent of Semitic or Semito-Negrito culture from the north into the interior has been overrated. The centers of culture in Africa along the Mediterranean have never contributed elements of profound or vital influence to the native Africans. The reason is that the north coast, with the exception of Egypt, so woefully limited in extent of territory, never developed a civilization peculiarly its own, because it lacked a hinterland. The Sahara interposed its desert barrier. Mediterranean forms of civilization failed to exert influence upon the Sudan races for the same reason that the Hottentots lacked many an African element of East Indian civilization. In the latter case, too, a Sahara interferes, the Kalahari Desert. The east side, then, is the open door of the African continent. If it was so hard to penetrate to the interior from the west, while the east side never offered real difficulties, it was because advance from the west was tantamount to "swimming against the tide." So the picture of the contraction or repression of the area of Malayo-Negrito culture dispersion as a mechanical process stands clearly revealed before us.

But the essential factor in these processes lies deeper, in the nature of the civilization, in its physiologic structure. If we consider the peculiarity of the Malayo-Negrito culture elements dependent upon the material, we see vegetable substances everywhere. Witness the shields, the bow, the drums, the stringed instruments, the costumes. But the prominence of vegetable material in all the manifestations of Malayo-Negrito culture is less noteworthy than the lack of animal substances. The only exceptions are shells, fish bones, feathers, and lizard skins, that is to say, material of minor consequence, such as is within the reach of all island races. On the other hand, look at the culture forms of East, North, and South Africa—everywhere decidedly preponderating use of hides, sinew, hair. We can discern the deeper law of the distribution of these two forms of civilization; wherever Malayo-Negrito culture still exists, cattle breeding is not carried on to any great extent. (Goats need not enter into the account.) However we have not yet reached the fundamental explanation.

An examination of Malayo-Negrito characteristics with a view to origin and development points to definite plants. It is not possible for me to substantiate this statement here, lacking, as I do, space and illustrations. Among weapons the bow, among smoking utensils the Malayo-Negrito pipe indicates evolution from the bamboo. This material, which plays so gigantic a rôle in the economy of Malayo-Negrito Oceania, is replaced in Africa, often very inadequately, by ribs of banana leaves and leaf stems of the bamboo palm, or Raphia vinifera. Study of plant geography accordingly leads to the region where the use of the bamboo is pronounced in the manufacture of objects illustrative of native culture, that is, to Indo-China and the Malay archipelago.

Again, the iron blade used on the Malayo-Negrito ax of the Africans we found to be a derivation from shell blades, such as are met to this day in Melanesia. Valuation in kauris (cowry shells)—that is, those of East Indian origin—disappears in the Kongo Basin, and here and there we meet with ropes of shell coins made, like the Melanesian divarra, of *Achatina monetaria*. On the island of Fernando Po and in Angola they passed for money so late as the time of the first European arrivals; on the upper Ituri, Stuhlmann found them used as jewelry, and we are familiar with similar ropes in Loango and on the Kongo. So we have the remains of island civilization on the mainland. But the island and fisherman's civilization of Oceania has bequeathed many another legacy to the Africans. One of them is pile dwellings, whose degeneration on the continent we have referred to. The present discussion enables us to understand their slow disappearance. Finally, the culture of a fishing community is on all sides characterized by mesh work. The well-known nets carried by the men of New Guinea recur in the culture of West Africa. In New Guinea the net is used as clothing, and in the whole of West Africa we hear of the netted jerseys of the disguised.

If, on the other hand, we devote attention to the nature, the physiologic structure of the culture forms adjacent to the West African culture area, we shall recognize the significance of the continental civilization. In the first place, the breeding of cattle exercises deep influence upon the compass and intent of culture. The remarkable migratory life of the Africans is explained by the half-nomadic occupation of cattle herding. Their food consists mainly of flesh. On the other hand, it is a fact generally overlooked that the West Africans on the whole are vegetarians. Furthermore, the institutions of the family and of the state among the real Indo-Africans or Indo-Negritoes point to the patriarchate, a phenomenon concomitant with cattle-breeding, which is opposed to excessive crossing. In the West African circle, again, the matriarchate, the family grouping that obtains among island races, hence among the Oceanians, is possibly to be classed among Malayo-Negrito characteristics, in particular when accompanied by exogamy.

The very views of life entertained by the two groups show similar opposition in their physiologic essentials. Restless nomads are seldom reminded of their past; hence the tendency toward the worship of manes and of ancestors is slight among them. On the other hand, turn in what direction they will, island races encounter traces of their former life. The natives of Oceania know some tale to tell of every locality; likewise, the mythology connected with manes flourishes in West Africa.

Thus the features of division and of union stand out from the gray background. For Africa is a continent like unto itself alone, and it exercises leveling power like none other. At a casual glance, then, African forms of culture may seem to differ but slightly from one another. But our study of the manifestations of life proves that cycles of thousands, yea, of hundreds of thousands of years—for thus only can we properly express our ignorance of how time must be computed in such cases—have not succeeded in obliterating the identity of original forms and traits.

4. The culture forms of Africa described in the above show the following sources:

1. Negrito culture forms.
2. Malayo-Negrito culture forms.
3. Indo-Negrito culture forms.
4. Semito-Negrito culture forms.

The remains of Negrito civilization are very slight. In fact, they will become clearly visible only when south Asiatic and Oceanic forms of culture have been thoroughly investigated and classified. At present I can set down the following with certainty as marks of Negrito culture: The staff as a javelin, the staff as a weapon of defense, the staff as musical instrument (Klangstab). The area of diffusion of these elements, though often modified almost beyond recognition, I can prove to be the whole of Africa almost as fàr as the Sahara. I say "almost," for they seem to be absent from the West African sphere of civilization. It would be improper to connect Negrito culture directly and unreservedly with the so-called dwarfs—the little yellow race of pygmies. These Bushmen have everywhere accepted the civilization of their surroundings. (Parasite culture!)

With regard to the three other sources, the conspicuous thing is the addition of "Negrito" in each instance. This I believe to be in accordance with the facts of the case, for wherever Africa has been subjected to influences from Asia and Oceania there has been an admixture of Negrito culture. The importance of Malayo-Negrito culture will be considered presently. East Indian spheres of culture in the period before their rise were obviously impregnated with elements of Malayo-Negrito extraction. But North African culture elements all point to reciprocal relations with the continent.

When we come to the consideration of Malayo-Negrito culture, a glance at foreign relations is necessary. In the article in Petermann's Mitteilungen, Part IV, the attempt was made to give a cartographic representation of these affinities. Three zones, or belts, are distinguishable. The southernmost embraces Australia and the southern point of Africa. Here Malay influence, though slight, is unmistakable, but the conspicuous fact is the preponderance of Negrito culture elements. It is, therefore, the region—perhaps the "region of remains"—of the old Negrito civilization. The zone farthest north is defined naturally by the linguistic uniformity of all the races. It includes the Hovas of Madagascar, the Indonesians, Micronesians, and Polynesians, hence is the domain of young Malay civilization. The third of the Malayo-Negrito zones lies between the other two, and comprehends the West Africans, the West Malagassas, some Indonesians, the lesser Sunda islands, the Moluccas, and the Melanesians. It is the territory within which but one race has been crossed with another.

The situation of these three zones is the key to our problem. Youth, hence unity of language, is the characteristic of the northern zone; age, indicated by repression to the very limits of settlement, is the mark of the southern zone. The middle belt is at once the richest and the most uniform. It bears neither the senile expression of the Negrito zone nor the youthful, impetuous character of the Malay zone, but that impressed by a great and serious past.

In addition to the above, we must bear in mind the situation and surroundings of the first source and center of Malay culture forms; that is, Malacca, or more properly, perhaps, Indo-China. The reader will permit me to point out a remarkable parallelism. As Farther India thrusts out its elongated form into a sea of islands, opposite to which is a continent, while a peninsula of firmer outline, East India, lies on the west, so Greece, opposite to Egypt and to the east of Italy, sends its point into an archipelago.

History proclaims the important bearing of the peculiar geographic position of Greece and Italy upon culture, yet surely the history of Mediterranean civilization neither began with Egypt nor ended with Rome. If, then, we speak of the civilization of the Middle (Mediterranean) Sea, we may equally speak of the civilization of the Middle (Indian) Ocean. In intercourse with Egypt, Greece rose to supreme position as a civilizing and colonizing power, covering the central and eastern shores of the Mediterranean with its stations. A like point of view gives us a clue to the course of Malayo-Negrito culture, whose influence is demonstrable on all the shores of the Indian Ocean. Malay culture acquired the faculty of spreading to so great an extent that it entered into alliance with Negrito culture as Greek intermingled with Egyptian civilization. The rise of every form of civilization is preceded by some such impregnation. To avoid misapprehension, I emphasize the fact that the young Malay civilizations, characterized by linguistic sameness, owe their rejuvenation to a recent epoch.

This comparison of geographic positions furnishes a clue not only to the spread of Malayo-Negrito civilization as far as West Africa, but also to that of Indo-Negrito relations. The ancient civilization of India may properly be compared to that of Rome. The culture that brought the Africans millet and iron was solid, practical, robust in every respect.

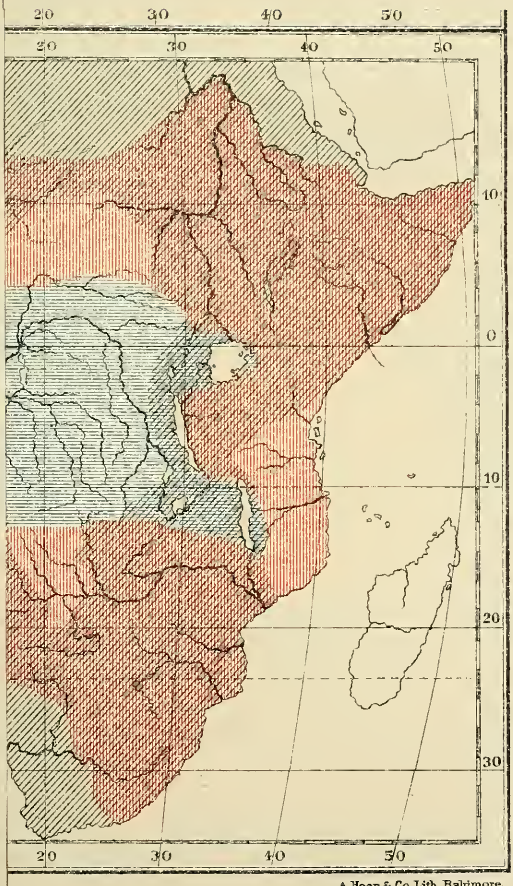
Finally, with regard to Semito-Negrito civilization, I should like to utter a caution against overestimating it. In the material products of civilization its influence is barely traceable. It introduced neither the plow nor solidly built houses to the part of the continent that is genuinely African, yet this should have been the task of the Semitic culture agents. Whatever they have imported, such as the straight sword, the double-limbed bow, the round shield, etc., did not penetrate far to the south and was not original with them.

In closing this article I beg leave to state its purpose emphatically. It was written not to array arguments substantiating the correctness of certain new points of view, but to sum up these points of view in a brief presentation. If I have succeeded in showing how the new method should be wielded and what sort of results can be reached by its application, it has fulfilled its purpose.

The African culture forms.

[From L. Frobenius; Ursprung der Afrikanischen Kulturen.]

Form of life.	Position.	1. Negrito culture.	2. Malayo-Negrito culture.	3. Asiatic culture.	4. African culture.
I. Degeneration and stagnation in nature and distribution. (Wood and bamboo culture forms.)	(A) Remains occurring sporadically. No defined tendency of distribution	1. Staff shield. 3. Club and staff as missiles, boomerang. 5. Staff as musical instrument (Klangstab). 6. Screen, circular hut, earth couch.			
NOTE.—Development of forms without reference to geographic distribution.	(B) Distribution over the western territory, the main abode. Unimportant remnants on the east coast.		1. Shield with plaited covering. 2. Bamboo bow. 3. Bamboo knife, — — —. 4. Bamboo lute, etc., tangola, etc. 5. Bamboo drum, wooden kettledrum, marimba. 6. Hut made of mats, pile dwelling. Appendix: Banana culture, palm-fiber costumes, bamboo pipe, reed arrow, etc.		
II. Vigorous development in nature and distribution (leather and hide culture forms).	(A) Distribution about the northern axis.			1. Round leather shield. 2. Leather bow. 3. Sword, saber, stiletto. 4. Violin, guitar. 5. Earthenware bass drum, iron kettledrum, tambourine, etc. 6. Tent, tent hut, brick and stone buildings. Appendix: Cultivation of millet, plow, cattle breeding, leather costumes, leather arrow, etc.	3. Iron missiles.
NOTE.—Development of the forms corresponding to geographic distribution.	(B) Distribution about the southern axis.				1. Hide shield. 2. Flattened bow. 3. Spearpointed knife. 4. Gubo, Gora. 5. Hide as drum, mortar drum, pot drum. 6. Southern cone-shaped hut.



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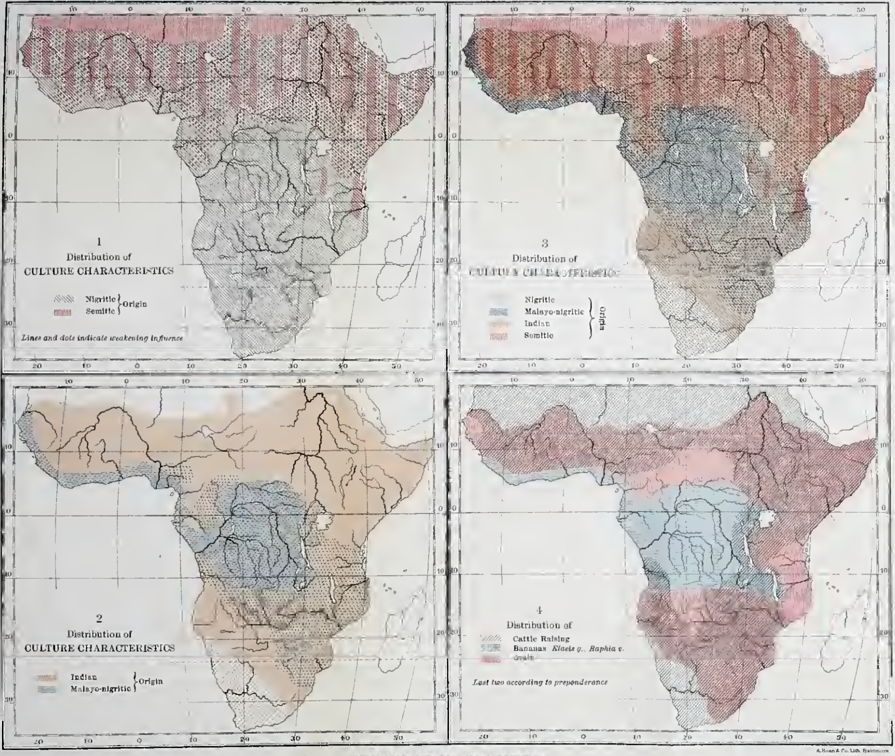

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ORIGIN OF AFRICAN CIVILIZATIONS

DOGS AND SAVAGES.[1]

By Dr. B. Langkavel, Hamburg.

INTRODUCTORY NOTE.

In submitting to the readers of this journal the results of my studies upon the relations between savages and the most important and widely diffused of our domestic animals, I shall cite the sources of my information. Of the 114 longer or shorter papers and notices that I have written during the last fifteen years concerning the dog, 22 treat of the Asiatic races, 4 of the African, 11 of the American, 4 of the Austral-Polynesian, the remainder of the European. In all these papers my principal aim was to determine the different races correctly. Whatever I have gathered during this period from the widespread literature of geology, ethnology, and zoology concerning the relations between dogs and savages will be presented briefly in the following pages.

The oft-raised question concerning the original home of the dog is, so far as our knowledge reaches, well answered by the remark of Alfred Nehring,[2] that "our most important domestic animals have generally no single home," a saying that might in a certain sense be paralleled by the old tradition of the Flatheads and others, that "when the son of the Sun came to earth he was accompanied by a dog."[3]

The dog has been scattered over the entire earth for an immeasurable length of time. Only in a very few localities is he entirely wanting or very rare. Of these I have spoken at length in a paper published in the journal *Der Hund* of April 1, 1886, and I will state here what has since become known to me, as it is important for the later discussion of the question. In Asia the dog is very rare at Tarim, according to Prschewalsky.[4] At Flores dogs and horses are so seldom seen that

[1] Translated from the Internationales Archiv fur Ethnographie, Bd. VIII, 109–149.

[2] Zeitschr. fur Ethnologie, XX, 230.

[3] Lord, The Naturalist in Vancouver Island, II, 240.

[4] Petermann's Ergänzungsheft No. 53, p. 13.

at sight of them the natives seek refuge in trees;[1] and, according to Dr. Claus,[2] a similar fear is shown by the South American Suyas. In Kagaruma-Shima (Liukiu Islands) there are neither hares nor wild pigs, on account of which the people have no need for hunting dogs;[3] the same is the case at Minicoy,[4] in the Maldive Islands,[5] at Hormuz, in the Persian Gulf,[6] and on the island of St. Lawrence, as Nordenskiöld tells us.[7] In South America no dogs are found with the Bakairi, Manitsanas, and Bororo;[8] in Africa there are none on the Comoro Islands,[9] nor are there any among the old Tasmanians.[10] In ancient times none were allowed on the island of Delos.[11] Crawford controverts the statements of Ritter,[12] Lassen,[13] and Kolenati[14] concerning the absence of Canidae in western India.[15]

Osseous remains of dogs are found in that stratum of the earth's crust from which we obtain information concerning men, animals, and plants that existed long before the historical period. Prehistorical discoveries, chiefly in Europe, show us the dog already, at that time, affecting and influencing in various degrees the life of man. Deep scratches made by knife-like instruments found on the bones of young and old dogs, bones broken in pieces, skulls cracked with stones to get at the sweet-tasting brain, lead us to recognize these relics as food rejects, and I might now affirm with still more ground the view I published in Ausland[16] fourteen years ago, that man, during the first stage of his earthly wanderings in a constant struggle for existence, obtained control over the dog as over other animals, merely for food purposes. The food question is the chief one both for animals and man;[17] even at the present time anthropoid apes and the lowest races of people show that they can live on fruits and roots of the woods and fields, on insects (caterpillars, crickets, locusts, ants, larvae of every kind), worms, mus-

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[1] Zeitschr. der Ges. f. Erdkunde, Berlin, XXIV, 113.

[2] Deutsche Geogr. Blätter, 1889, 226.

[3] Mitth. der Deutsch. Ges. f. Natur- und Völkerkunde in Ostasien, H. 24, 1881, pp. 142, 146.

[4] Peterm. Mitth., 1872, 297.

[5] Ausland, 1887, 763.

[6] Natur, 1893, 273.

[7] Umsegelung Asiens, II, 245.

[8] Karl v. d. Steinen, Durch Central-Brasiliens, p. 290; Unter den Naturvölkern Central-Brasiliens, p. 483; Rodenberg's Deutsche Rundschau, 1 October, 1892; Zool. Garten, 1889, 103; Verhl. der Gesel. f. Erdkunde, Berlin, XV, 376; Revue Coloniale Internat., III, 536.

[9] Ausland, 1887, 509.

[10] Erzherzog Ludwig Salvator, Hobarttown, p. 15.

[11] Strabo, ed. Kramer, vol. II, p. 418, 14.

[12] Erdkunde, V, 258.

[13] Ind. Alterthumskunde, I, 301.

[14] Hocharmenien, p. 86.

[15] Hist. of Ind. Archipelago, p. 428.

[16] 1881, 658, and after that, Gartenlaube, 1882, No. 44.

[17] Louis Bourdeau, Conquête du monde animal.

sels, lizards, etc. Where necessity requires it, there is, as is too often forgotten, nothing strange about this. The nature of man is such that he must either prey on the animal world or perish from want, hunger, and cold. As soon as he learned to use, for defense or attack, other weapons than his own limbs, he must have begun to bring the dog nearer to him as his helper in the struggle. From the earliest stage when the dog was used merely as food, the custom of eating him in one way or another has survived among a great number of peoples; and the number of dog-eating races of which I published a list in 1881 could now be easily increased to 200, although there would then be included such tribes as have been compelled to adopt the custom from hunger or because of hostile neighbors. When Fr. Rätzel[1] remarks: "One may assert in general that man, in the lowest grade of civilization, always first gratifies his pleasures, and only takes up useful things when necessity drives him to it; thus we see the dog as his only constant companion at a time when his use was very limited," he is speaking of a certain stage of civilization like that, for instance, of the Chambians, who domesticate divers animals for amusement.[2] Specially gifted men may early have attempted the exhibition of animals, as we read, not to mention early European sources, in Maury's[3] report on the Tchoude in southern Russia and Siberia. Waitz (VI, 786) mentions a dance in which adults introduce dogs in order to teach boys to acquire control over them, and this may perhaps be considered a survival from that distant time when men strove by means of cunning (traps) or arms, to capture these animals.

It is a noticeable fact that may be explained to some extent on phylogenetic grounds that the primitive dwarf peoples had but one domestic animal, the dog. The Batua, from Lubi to Taganyika, have, with the exception of a few fowls, no domestic animals but the dog, and, indeed, one of the remaining breeds of African dogs is a quite serviceable, well-marked, greyhound-like species, very much used for hunting.[4] The Bushman has no other animals than the dog and the louse, and only the first is possessed by the dwarf-like Veddahs of Ceylon, and the Negritos of the Philippine Islands. The high relative standing given to the dog by all these peoples is explained at once by their occupation of hunting, which early caused them to consider the most suitable animal for the chase, which therefore limited their domestication of animals to the dog, who thereafter had no rival with whom to share his master's care and attention. The most significant fact shown by this continued limitation is that stocks of a certain culture stage remain stationary at this point. As the dog is the oldest domesticated

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[1] Völkerkunde, I, 57.

[2] Verhl. d. Ges. f. Erdk., Berlin, XVI, 456; also v. Martius, Beitr. zur Ethnographie, I, 17.

[3] Archiv f. Anthrop. III, 365.

[4] Zeitschr. d. Ges. f. Erdk. Berlin, XXVIII, 113, et seq.

animal, so the peoples that extend their training to no other animal, probably from natural incapacity for progress, remain at the lowest and oldest stage of the development of man. In other words, they appear as primitive races.

In those places where dog-eating is the custom, and where young and fat dogs are considered great delicacies, much care is bestowed on the young puppies, and only too frequently have travelers seen young mothers give them the breast. Thus, in New Guinea[1] and in Australia the father even kills his own child that the mother may give suck to a puppy, and similar cases have been often noted[2] at Tahiti,[3] Hawaii, and the Society Islands.[4] In upper Burma, in 1879, Joest saw in the bazar in Thayetmyo a young Burman girl nursing at one breast her own offspring, at the other a small dog, and in Mandalay he was assured that young mothers reckon it an honor to give suck to little white elephants; that the Ainu women of Yezzo nurse little bears in the same way is well known.[5] Wrangel[6] was the witness of an incident in the polar regions similar to that which Joest saw in Burma. The women of the Paumaris in Peru nurse dogs and monkeys as do those of Dutch Guiana and others.[7] In Gran Chaco the women willingly nurse young dogs, but never motherless babies.[8] Frequently the reverse condition exists; for example, Chinese women of Java give their children female dogs from which to nurse.[9] * * * But the dog is handled and well cared for not only in those regions where he is an important article of food, but still more frequently when he is a helpful hunting companion, as with the Wagandas.[10] The Shilluk never treat their dogs badly; neither will they allow anyone else to do so.[11] The beautiful "slugi" is the favorite of the Arab and his children,[12] and is treated well by the boys.[13] With the Battaks each boy has a particular dog as a "kaban," or companion, that is highly regarded even when very old.[14] With the Patagonians favorite dogs are formally adopted.[15]

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[1] Ch. Lyne, New Guinea, p. 34; Ausland, 1866, 570 Finsch, Samoafahrten, p. 53, and in the Annalen des naturhist. Hofmuseums Wien, III, No. 4, p. 322; Zeitschr. f. Ethnologie, XXI, 13.

[2] Darwin Var., I, 48; Waitz, VI. 779; Keppel, A visit to the Indian Archipelago, II, 172; Erzherzog Ludw. Salvator, Hobarttown, p. 65.

[3] Peschel's Neue Probleme, p. 44; *cf.* Neue Deutsche Jagdz., VIII, 231.

[4] Archiv. f. Anthropol., IV, 219.

[5] Ausland, 1886, 360; Der Hund, XIV, 16.

[6] Reise, I, 214.

[7] Ausland, 1886, 265; 1887, 578; Kappler, Holländ. Guiana, p. 116, and Hartsinks in Beckmann's Physikal.-ökon. Bibliothek, XIV, 19.

[8] Waitz, III, 480.

[9] Diener, Leben in der Tropenzone, p. 72.

[10] Zeitschr. f. Ethnologie, II, 138.

[11] Jahresbericht der Geogr. Ges. Bern, p. 105.

[12] Kobelt, Reiseerinnerungen aus Algier, p. 304.

[13] Baumann, Fernando Póo, p. 88.

[14] V. Brenner, Besuch bei d. Kannibalen Sumatras, p. 251.

[15] Behm, Geogr. Jahrb., V, 142; *cf.* Ausland, 1888, 349.

Just as the dog was used by later prehistoric man for hunting, he is also used by the savages of to-day, and in all four quarters of the globe we find him widely distributed, though in different grades of development. It would be a waste of space if I should here enumerate all peoples who hunt with more or less highly trained hunting dogs, but this subject belongs to a treatise on the science of hunting. A few examples will be sufficient to show how varied are the methods of hunting in Australia,[1] New Guinea,[2] among the Tehuel of Guanaco,[3] in America, in Matto Grosso,[4] in Ecuador.[5] The natives of Haiti raised a breed of small dogs for hunting on the island.[6] Even before the time of Columbus the Tarumas possessed, as they do now, excellent hunting dogs which they kept, when not in use, in a kind of cage.[7] The Bonny negroes bury their hunting dogs and in the Bushman village of Guidappou talismans are hung around them.[8] For the hunting methods of the Koluschans, Hurons, and Tlinkits, see note.[9] In North Borneo the people land from five to seven dogs from boats in different places and learn from their bark where a boar is to be found, land there and kill him with spears. In the south of this island the flesh is separated from the bones of this wild animal and fastened to a tree; the dogs are then set onto this meat to make them courageous.[10] The hunts for stags and boars by the Bagobos and on Peel Island are also characteristic.[11] Savages have never descended to the mutilation of hounds hunting off their ground, as was practised in Europe in former centuries, the English law of the time of Henry VII providing that the left leg should be cut off, and the ordinance promulgated in 1702 that one paw or all the claws of one foot be removed.[12]

Castration has been practiced on dogs from an early date, for different purposes, and in countries far distant from each other, for example among the Kamchatkans,[13] the residents of Sakhalin,[14] and in Togoland.[15]

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[1] Waitz, VI, 729.

[2] Finsch, N. und seine Bewohner, p. 69.

[3] Zeitschr. d. Ges. f. Erdk. Berlin, IX, 345; Giglioli, Viaggio intorno al globo, p. 968.

[4] Zeitschrift, *loc. cit.*, V, 249.

[5] Simson, Travels in the Wilds of Ecuador, p. 169; Hassaurek, Vier Jahre unter Spanisch Americanern, p. 123.

[6] Oviedo, XII, 5; Waitz, IV, 323; Tippenhauer, Die Insel Haiti, pp. 213, 316, 374; Journal Anthrop. Institute, London, 1887, February, p. 272.

[7] Darwin Var. I, 23, 25; II, 276.

[8] Peterm. Mitth., 1862, 250, 247; Kappler, Holländ. Guiana, p. 80, and concerning the hunting hounds of the Warraus and Waikas, see further R. Schomburgk, Reise in Brit. Guiana, I, 199.

[9] Zeitr. f. Ethn., II, 316 and XVI, 234; Waitz, III, 87; Krause, Die Tlinkit-Indianer 5, 89; Deutsche Geogr. Blätter, IX, 224; Karr, Shores and Alps of Alaska, p. 148.

[10] Geogr. Proceedings, London, X, 6; Mitth. Geogr. Ges. Jena, VI, 99.

[11] Zeitschr. f. Ethn., XVII, 22; Hawks, Exped. of an American Squadron, p. 233.

[12] The Nineteenth Century, 1891, January, p. 116; H. Biernatzki, Schlesw.-Holst, Lauenburg-Landesgeschichte, II, 1847, p. 80.

[13] Gilder, Ice- Pack and Tundra, p. 17.

[14] Poljakow, Reise nach S., p. 42.

[15] Mitth. von Forschungsreisen in Deutsche. Schutzgebieten V, 12.

Fishing is, as is well known, eagerly pursued by many hairy animals, and by the dogs of northern regions especially in summer, thereby saving their masters the trouble of feeding them. I have written two papers[1] on the subject of fishing dogs, and in the second I mentioned, from the work of Howard,[2] the skilled methods of the Ainos of Sakhalin which considerably excel those of the English fishermen of Colvyn Bay on the coast of North Wales.

As draft animals dogs are attached to vehicles both on water and on land. As with us canal boats are drawn on rivers by means of a rope by people on the bank, so in eastern Siberia they are drawn by dogs, and indeed four dogs drag a boat regularly on the Yenisei from Troizkek cloister against the stream, and do it more easily than four of the small native horses.[3] They are used similarly—of course constantly only in the summer—by the Jukahirs,[4] the Giljaks on the Amur,[5] and the Kamchatkans.[6]

But this use of the dog is not as general as its employment as a draft animal on the land, concerning which Kohl has given us a tolerably general idea,[7] while the works of Lord and Baines are exhaustive and instructively illustrated.[8] The treatment which the poor draft dogs have to endure from us is discussed in the "Neue Deutsche Jadg-Zeitung" (XIV, 157). In this first decade of this century, Humboldt[9] refers to the significance of similar folk customs, and Yule[10] has made the observation that dog sledges are now used in Asia as far south as 61° 30′, but in the eleventh century they were also in use between the Dwina and the Pechora. According to Ibn Batuta,[11] they were used in the fourteenth century in the Land of Darkness, in Bulgaria (the old Bulgaria in central Russia), where the people drove with three dogs abreast and one leader. According to Langmantel,[12] "There are in these countries Wassibar dogs that draw carts in summer and sledges in the winter, and are as large as a donkey; and the people in this country eat dogs." Dogs are still sometimes used in some regions of Poland and in the northwestern provinces of Russia to draw small loads, but such a custom is not general,[13] and the animals are also too weak, but the comparatively small Siberian dogs, in spite of their

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[1] Der Hund 1884, No. 48, and Schweitz. Zentralbl. f. Jagd- u. Hundeliebhaber, 1894, No. 5.

[2] Life with the Trans-Siberian Savages, 1893, p. 51 et seq.

[3] Müller, Unter Tungusen und Jakuten, p. 180.

[4] Wrangels Reise, I, 214.

[5] Journal Geogr. Soc. London, 1858, 396; Peterm. Mitth. 1857, 314.

[6] Peterm. Ergänz. Heft No. 54, 16.

[7] Der Verkehr und die Ansiedlung der Menschen, p. 75.

[8] Shifts, Experience of Camp Life, pp. 353, 354, and 358.

[9] Reise in der Aequinoctial Gegenden, IV, 585.

[10] Book of Marco Polo, II, 43.

[11] Lee, The travels of J. B. p. 78.

[12] Hans Schiltbergers Reisebuch, p. 39.

[13] Russische Revue, XI, 443.

greater leanness, accomplish considerable, their strength and perseverance being astonishing. Kennan says:[1] "I drove a team of nine, in twenty-four hours, over 150 kilometers; they often pull for forty-eight hours with no food except one fish of 1½ or 2 pounds. In the west the dogs are made to pull with the hips, in the east with the breast."[2] According to Erman,[3] the tent-living Samoyeds use only the reindeer as a draft animal, but the remainder of the Samoyeds and the Yakuts use dogs, and indeed each one can pull an average weight of 20 to 35 pud.[4] Concerning Tobolsk, says the Abbé Chappe d'Anteroche,[5] "The only traveling is by dogs, which are harnessed to sledges." In the province of Jenesei there were in 1864, in the capital, 115 sledge dogs; in the city of Turukhansk, 43; in the entire district, 860.[6] According to Finsch,[7] a draft dog costs, in Beresovskoe, 2 roubles. They are so harnessed that the drawing strap passes from the sledge between the legs of the dog and to a ring fastened around the body and to the tail; they draw, therefore, with the hips. Still farther east the number of sledge dogs is so much greater that in 1880 there were in Yakutsk 3,792,[8] although many Yakuts still travel with reindeer.[9] Wrangel[10] already observed that on the Kolyma male dogs exclusively are used for pulling, part of the females being saved for subsequent breeding purposes, and the rest drowned; he was very much astonished at the sagacity displayed by the leader. Along the Kolyma the inhabitants are also of the firm conviction that there the male dogs alone can thrive. Notwithstanding this any change for the better is made impossible, the people often enduring the pangs of hunger in order to support their dogs. Their number is estimated at 2,265, and since each receives 4 herrings daily there are required during the year for them alone 3,306,900 fishes. Between the Lena and Bering straits 12 dogs run before every "uarte" and cover in an hour on favorable ground 5 nautical miles. At Shigansk a good leading dog is worth from 40 to 60 roubles.[11] The descriptions of men and dogs during the winter at Ussuri are very interesting.[12]

The Kamchatkans are the recognized masters in dog-sledge driving

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[1] Tent Life in Siberia, p. 124.

[2] Hiekisch, Die Tungusen, p. 78.

[3] Reise um die Erde, I, 701, 655, 296.

[4] Peterm. Mitth. 1872, 361.

[5] Voyage en Sibérie I, 202.

[6] Peterm. Mitth. 1867, 330.

[7] Reise nach Westsibirien, pp. 367, 590; Ausland 1882, 307.

[8] Russische Revue XI, 443.

[9] Peterm. Ergänz., Heft No. 54, 26; von Middendorff, Reise IV, 1295, et seq., 1330 et seq., Gilder, Ice-Pack and Tundra, p. 301; Seebohm, Siberia in Asia, p. 43, concerning those in Turschansk; Buletschef, Reisen in Ostsibirien I, 73; Erman, Reise um die Erde II, 427, concerning the dog sledges at Ochozk.

[10] Reise I, 212.

[11] Peterm. Mitth. 1879, 420, 168; 1887, 120.

[12] Extraits des Publications de la Société Imp. Geogr. de St. Petersbourg, 1859, 78.

and in breaking in dogs. They also use only the males, the team consisting of 12 besides the leader; on each dog falls the average load of 1 pood (36 pounds) and in twenty-four hours he is expected to cover a distance of 150 versts (100 miles)[1]. Krascheninnikow the elder[2] remarks that in going down hill only one dog is used, and Wrangell[3] that with dogs not fully trained only 10 to 15 versts (7 to 10 miles) distance is covered in a day, at first; he is also of the opinion that the use of dogs as draft animals originated on this peninsula, and that earlier all peoples of northeastern Asia drove only reindeer. The number of draft dogs is approximately 10,000, an average of 9 to each family, and the price is from 3 to 25 roubles each.[4] Here, as with the Tchuktches, they are urged on by a rattle.[5] In recent times the number of dogs in a team, the size of the load, and the price of dogs seems to have changed greatly, for Gilder[6] saw in Petropaulovski 6 drawing a sledge with one person; a team of 9 good dogs was expected to pull 600 pounds, while with the Eskimos 9 dogs pulled a load of 1,800 to 2,000 pounds 15 to 20 English miles a day for weeks, and even for months. He bought 40 full grown dogs and paid for each $7.50. Yerman and Bennet[7] drove in sledges with 4 or 6 dogs. When von Dittmar[8] lived there, there was a team of 8 large, black dogs with a fox-red leader, that alone was worth 25 roubles, while the other 8 together were worth only 40 roubles. Each one had a leather neck strap, therefore pulling with the breast and neck, and all were governed solely by the voice.

Concerning the draft dogs of the Tchuktches, we learn through Wrangell[9] that not as on the Kolyma, always 2, but always 4 run abreast; through Hedenström[10] that they can, exceptionally, cover 200 versts (132 miles) in a day; and through Nordenskiöld[11] that they can pull for twenty-one consecutive hours without being unharnessed. There are also many draft dogs on Bering Island, 600 being used exclusively to haul driftwood on sledges.[12]

Let us return from here over the island of Sakhalin to Russian Asia, in order to observe several races who drive mostly draft dogs of a smaller breed, as in the Amur coast lands,[13] or as the Tunguses and

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[1] Peterm. Ergänzungsheft, No. 54, 16; Zeitschr. f. allg. Erdk. N. F., XVI, 315.

[2] Beschriebung des Landes K., p. 237, 18.

[3] Reise, II, 262, 25.

[4] Ausland, 1891, 694.

[5] Zeitschr. f. Ethnologie, 1872, 238.

[6] Ice Pack and Tundra, p. 17.

[7] Journal of Voyages and Travels, I, 478.

[8] Reisen und Aufenthalt in Kamtschatka, p. 160, in the Beitr. zur Kenntn. des russ. Reiches.

[9] Reise, II, 226.

[10] In Erman's Archiv., XXIV, 132.

[11] Umsegelung Asiens, I, 457; cf. Ausland, 1882, 699; Deutsche Geogr. Blätter, V, 119.

[12] Deutsche Geogr. Blätter, VIII, 234.

[13] Radde, Reise im Süd v. Ostsibiren, p. 86.

Lamuts, who also drive reindeer.[1] In the island of Sakhalin all the tails of the males are cropped to remove a hindrance in pulling.[2] The Oroks of to-day are "a mongrel race of reindeer-driving nomads and stationary dog-owning fishermen."[3] The draft dogs of the Giljacs are described by H. Russell Killough,[4] a traveler among the Yukahiras, in Petermann's Supplement, No. 54, 17.

In Alaska the dogs of a team, usually 4 abreast, travel so closely one behind the other that amputation of their tails is found to be necessary.[5] * * * Krause[6] writes concerning the teams of the Tlinkits, Boas[7] of those of the natives of Baffins Land, Leland and Kane[8] of the Ottawas of the northern lakes. Formerly, dog sledges ornamented by three bells were in use at the head waters of the Mississippi, sledges were also used by the Thickwood Cree Indians in winter.[9] In Labrador the sledges are drawn by from 12 to 20 male and female dogs with 2 leaders, on a 20 to 30 foot trace, while the other dogs of the team are traced short. During the thawing weather in the spring the dogs wear regularly made shoes of seal skin, in which are cut holes for the two front toes to give freedom to the nails. Above the toes the leather is tied fast. It is easily conceived that the animals become exhausted after three hours during these thaws. With lighter loads, 3 to 12 animals are used before the sledge, with a leader attached to a trace 5 meters long.[10]

The Eskimo dog, which Le Peyrère[11] described in 1647, saying that he was very large and was used like a horse, is found, according to Robert Brown,[12] as far north as man goes, but is not used by the Eskimos farther south than Holsteinborg, because the ocean does not freeze in winter sufficiently hard to use sledges on it. If this dog should become extinct, the Greenlander must also perish; this event is more certain than the extinction of the prairie Indians after the death of the last buffalo. In Greenland 6 to 8 dogs usually go together; in order to break them of their obstinacy they are often beaten with a whip having a handle a meter long with 6 or 8 lashes

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[1] Ratzel, Anthropogeographie, II, 73; Peterm. Ergänz.-Heft, No. 54, 22; Peterm. Mitth., 1894, 135.

[2] Poljakow, Reise, p. 34, 42. Peterm. Mitth., 1881, 112.

[3] Poljakow, loc. cit. 95; Peterm. Mitth., 1893, Literaturberichte, p. 165.

[4] Seize mille lieues à travers l'Asie, I, 192.

[5] Peterm. Mitth., 1892, 137; cf. Bancroft, Native Races, I, 62.

[6] Die Tlinkit Indianer, p. 89.

[7] Peterm. Ergänz.-Heft No. 80, S. 7, and Boas in the Hamburger Nachrichten of 11, 1, 1889.

[8] Lelang, Fusang, p. 19. Kane, Wanderings of an Artist, p. 26.

[9] Waitz, III, 87; Lord, The Naturalist in Vancouver and British Columbia, II, 212–226.

[10] Peterm. Mitth., 1863, 125. Neumayer, Die Deutschen Expeditionen und ihre Ergebnisse, I, 173, 175, 183; II, 26.

[11] Relation du Groenland; cf. Nordenskiöld, Grönland, p, 420.

[12] Proc. Zool. Soc. London, 1868; cf. Peterm. Mitth., 1869, 463.

of walrus hide. Toward the middle of 1870 there were in all northern Greenland only 155 draft dogs.[1] On the northern shore of Hudson Strait and in King Williams Land the training is much better than in Greenland, because here the whip is seldom used, the refractory ones being punished with snowballs or, at most, by throwing sticks at them. Since it is assumed that the Eskimos owned dogs before their distribution was as wide as it is now, it is of interest to note the calls with which the different races, separated from each other, direct their animals. The Greenlander driver, writes Bessels, has only the call *i! i! i!*, short and spoken in falsetto. If he wishes the dogs to turn to the right, he cracks his whip on the left side, and vice versa. A short whistle means stop! This is the custom of all the inhabitants of the mission parts of Greenland. Those on the east shore of Smiths Sound call out a vehement *ha! ha! ha!* The method of guidance is as before mentioned. The stop call is *oh!* In the neighborhood of Ponds Bay the call for turning to the right is *wōa-ah-hă-hă-hă!*; for the left, *ah-wōa-waha!*; for halt, *oh!*

In Cumberland the sounds used are *wōa-hau-hă!* for the right, *ach-wōa-wit!* or *ach-wōa-wōa!* for the left, *hă-hă-ă* for urging onward, and similarly by the Itaners on Smiths Sound. Stop is *ōh!*

With the Eskimos on the Hudson Strait only the exclamation *ow! ow! ow!* is used, and those on King Williams Land know only the call *kgu! kgu! kgu!* The lash is unknown; one person goes before and leads the dogs or presses a stick of wood against the side opposite to the direction in which they should go. Bessels could not learn what was the custom in Alaska; many were of the opinion that they only heard curses, the embellishment of which depended on the obstinacy of the dogs or the irritability of the master. There also a person precedes the sledge. The number in a team varies between 4 and 8, and the load for a sledge is rarely more than 100 pounds. Well-kept animals cover, on a smooth road, 4 German miles an hour, and work twelve hours a day. After work they receive a pound of meat or fish. Neumayer remarks in another place that in Labrador the expressions *auk! auk! auk!* for to the right and *ra-ra-ra* for to the left are used. Many tribes of Eskimos show a pride in the fact that their dog teams are matched in color.[2] According to A. v. Etzel, the legend of the frozen sea, with the mention of dog sledges, known only in the northernmost colonies of South Greenland, is a striking evidence of emigration to South Greenland from the north.[3] In East Greenland the dogs have become extinct through sickness.[4] In conclusion, I will remark that the statements of

[1]Geogr. Proceedings, London, VIII, 175; Nordenskiöld loc. cit. 451; Klutschak, Als Eskimo unter E., p. 50; Geogr. Magazine, London, III, 179, with exact statistical data; v. Becker, Arktische Reise der engl. Yacht Pandora, p. 15; Bessel, Die amer. Nordpol-Exped., p. 141 et seq.

[2]Darwin, Var., II, 276.

[3]Zeitschr. f. allg. Erdk., N. F., XII, 418.

[4]Peterm. Mitth., 1871, 422.

Andrée[1] concerning the weight and speed of sledges, which differ somewhat from the above, are borrowed from John Crawford: "On the relation of domesticated animals to civilization," in the "Transactions of the Ethnological Society of London," II, 387–468.

Over the highest passes of the Himalayas and Thibet, where ponies and yaks can not venture, sure-footed sheep and goats are used as beasts of burden; sheep also are used in the country surrounding Bahia, South America, carrying a water jar on either side, up hill and down on very narrow mountain paths. Among the Indians of North America the dog is used as a beast of burden. Here, abused and harshly treated during life, he after death receives many honors—a truly human characteristic. At the time of Coronado, in the year 1540, he was used by a branch of the Comanches on the borders of the province of Durango for the transportation of hides, and is still kept for the same service.[2] Dogs are also used as beasts of burden by the prairie Crees in the Saskatchewan region,[3] as well as by the Atnátanas on the Copper River.[4] The ancient Peruvians also possessed such dogs.[5] In Asia the so-called Yencsei-East-Jaks[6] own pack dogs and in Kamchatka they traverse the mountains with light loads.[7]

However useful to man the dog may have proven himself as a hunting animal and beast of burden, yet many races of people left it to him to keep himself fat and in good condition as he did before their mutual approach. Fortunately, or unfortunately, he is an omnivorous animal, and this peculiarity makes him useful about the dwellings of larger or smaller settlements of man as a sort of street scavenger, sharing the office with vultures and the like, as is now the case in many eastern countries. What man no longer uses in his household—offal, dead animals, the bones of game, and in many places even human corpses—is thrown out and becomes food for the usually empty stomach of the neglected dog.

From classical antiquity we obtain many accounts of human bodies being thrown to the dogs to be devoured. Hector threatened to do this to Ajax and retracted his decision only because of Priam's tears. In Pohlman's paper on the excess of population in the great cities of the ancients, he has collected (p. 135) numerous passages from ancient authors showing this to have been done. In Asia we find, especially

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[1] Geogr. des Welthandels, I, 90,278.

[2] Humboldt, Essai politique, etc., III, 56; Reise in die Æquinoct. Gegenden, IV 585; Ansichten der Natur, I, 138; Bancroft, Native Races, I, 506; Mühlenpfordt, Versuch einer Schilderung von Mexico, I, 159, 177; Verhandl. der Ges. f. Erdk., Berlin, XII, 268; Ratzel, Vereinigte Staaten, II, 127.

[3] Hind, Canadian Red River Exped., II, 117.

[4] Deutsche Geogr. Blätter, IX, 224. Such dogs are figured in the oft-cited work of Lord und Baines, p. 361; V. Martius, Beitr. zur Ethnographie, I, 672.

[5] Waitz, I, 409.

[6] Radloff, Aus Westsibirien, I, 189.

[7] Kraschenninnikow, Beschr. des Landes K., p. 18.

among the Mongolian peoples, a complete indifference to the corpses of the "misera plebs." Before the year 1000 such bodies were given as prey to dogs—in Bactria according to Onesicritus, by the Hyrcanians according to Cicero, by the Sogdians according to Strabo. Th. v. Bayer[1] remarks that with the Kalmucks the bodies of the inferior classes are thrown after death, either into the water or out on the steppes for the dogs, vultures, etc., to devour; the better classes are, however, burned. A similar fate for the corpses of beggars in Kuldja is mentioned by Radloff[2]. In Urga, writes Prschewalsky,[3] the beggars have their nest-like beds in the market place. If one be about to die the dogs stand around him and wait for his last breath; he is then devoured. The dead of better classes are carried to the churchyard, dogs make up the procession and conduct the interment by means of their stomachs; only princes, gogos, and the highest lamas are really buried. In the well-known parable of Lazarus, who ate the crumbs which fell from a rich man's table, the dogs came and licked his sores. Would anything very different have befallen his body after his soul had flown to Heaven? If in the cities of China, according to Exner's account,[4] a beggar is dying, his identity is determined by officers, he is allowed to lie where he is, covered with mats held down with stones so that the dogs can not trouble him while alive; as soon as he is dead, however, they do their duty. The Kamchatkans believe in the life of the soul after the death of the body, and in the warm desire for this better life the father often allows his children to strangle him or to throw him to the dogs.[5] In caves of Poland thus far examined, traces of human industry have been found, but no human bones; this was held as a negative indication of the former occupation by Mongols,[6] who gave the dead to the dogs; a positive indication, however, was found in the names of places as *sagen* Mongolian *zagan* = white, *zebrzydowo*, *zebr* = wolf; *Karsy*, *Kars* = steppe fox, and many others. It is an interesting fact[7] that exactly in the center of the wide district through which we find scattered the place name *Psar* lies the dog field at Breslau, *Psie polje* = *Pasje polje*. The Polish chronologist, Vinc. Kadlubek, mentions this dog field at the beginning of the thirteenth century, and says concerning it that here in the year 1109 a battle took place between the Polish Prince Boleslaw and the German Emperor. The Germans were overcome, many were left lying on the battlefield, and the dogs swarmed from all sides and devoured the flesh until they were so gorged that they went mad; "caninum campestre locus ille nominatur." But an older chronologist,

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[1] Reiseeindrücke aus Russland, p. 435.
[2] Aus Westsibirien, II, 312.
[3] Peterm. Mitth., 1876, 8.
[4] China, p. 163.
[5] Peschel, Völkerkunde, p. 416; Zeitschr. f. Ethnol., III, 206.
[6] Prschewalsky, Reisen in der Mongolei, XIII, 5.
[7] Deutsche Rundschau f. Geogr. u. Stat., XV, 414.

named Gallus, who lived in the twelfth century and described this same battle, said nothing whatever of mad dogs.[1] There is no doubt that *Pasje polje*, or dog field, received its name before the battle of 1109, and is probably of the same ancient origin as the word *Psar*, belonging to so many places. In the good old times of the European Middle Ages we find numerous examples of the disposing of superfluous men by means of dogs. I instance only the well-known story of the Cid, who, when he could not get wood enough to burn his prisoners, had them torn to pieces by dogs.[2] In later times such bloodhounds were used in America for the execution of the most terrible deeds at the command of their masters.

We learn from Stanley that in Usukuma and Uganda dogs are used in battle. This was also the custom in ancient times.[3] When Marius overcame the Cimbri, his legions had also to fight against women and dogs. The Celts, as is shown by a bronze dog from Herculaneum, protected their dogs with spiked collars and metal breastplates. In the battle of Morat, in 1476, as the troops stood in order of battle, the dogs also began to fight. The Burgundian dogs were overcome by those of the Swiss, an omen of the overthrow of their masters. The Turks also placed dogs on their outposts. That the much prized Friedenhunde of our day were formerly educated as war dogs is proved by a widespread literature on that subject. In conclusion I will only say that on Robben Island (near Kapstadt) the bodies of people who have died of the smallpox are given to the dogs to eat.[4] * * *

The Eskimos of America pour the urine over the fragile roofs of their artificial snow huts, and thereby attract the caribou, which are greedy for the salt that it contains.[5] The chalky excrement, for which there is a special market in Berlin as the so called pharmaceutic gentian, is used by the peoples of western Asia for tanning. Its use spread from there to the dog-abounding city of Constantinople, for the preparation of morocco leather,[6] and great cargoes of it are sent from thence to the United States for the preparation of morocco.[7] The Tlinkits throw the bodies of dogs attached to long lines into the sea; after a time they become covered with dentàlia and are then withdrawn.[8] Concerning the use of the teeth for weapons and adornment, see below. According to Agatharchidas, Diodorus, and Strabo, the name Cynomolgi (dog's-milk

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[1] Röpell, Gesch. Polens, I, 670.

[2] Gartenlaube, 1893, 442.

[3] Journal Geogr. Soc. London, 1876, 28; Zeitschr. f. Jagd- und Hunde-Liebhaber, St. Gallen, 1892, 169.

[4] J. Stanley Little, South Africa, II, 274.

[5] Klutschak, Als Eskimo unter Eskimos, p. 131; Neumayer, Die Deutsch. Exped. und ihre Ergebnisse, II, 16.

[6] Olivier, Voyage dans l'Empire Ottoman, 1801, I.

[7] Zool. Garten, 1894, 55; Natur, 1892, 334.

[8] Krause, Die Tlinkit Indianer, p. 183, and for Alaska, Ausland, 1888, 970.

eaters) is applied by the inhabitants of Sierra Leone to the tribes who use the milk of swine.[1] According to Major,[2] in the neighborhood of Cape Branco men, horses, and dogs live for months on the milk of the most varied animals, as they also do on honey in South Africa.

Trade in dog's hides is carried on from northern Asia in two directions—either west to Europe or east to North America; and the farther they are carried the more expensive they become; for while in Obdorsk a good skin costs 6 roubles,[3] in the market of Charkow a black Siberian dog pelt is worth from 50 to 100 roubles.[4] In Paris the pelt is quickly tanned and prepared as fashion demands.[5] The greatest number of dogskins is, however, consumed in eastern Asia itself, though the trade there is now somewhat reduced. On account of the war with Japan, fewer marriages take place in thickly populated China. There were formerly brought to the young bride in Manchuria and Mongolia, as wedding presents, many dogs, which thick-haired curs the young husband took with his wife to his new home, then immediately slaughtered them and made from the skins carpets and bed covers.

The superfluous ones were sold to traders in Chinese ports, and thus dogskins of an annual value of nearly 2,000,000 marks were sent to the United States.[6] As in the Abyssinian monastery Zad' Amba the entire possessions of a pious brother consisted in the half of a goatskin—his carpet, his bed, his cloak, his all[7]—so also in China the poor and the beggars own nothing but a shabby dog skin[8] that they have found or that has been given them, and the middle classes complete their winter costume by a storm coat of dog or goat skin. The principal export town for colored skins is the port of Liao-ho, or Niutschwang, in Manchuria. It was formerly believed that these skins came from ownerless, wandering dogs, but the yellow book of the customs officer of that city at the end of the year 1880 shows that the production of hides is the work of a trade organization. In all Manchuria and on the eastern borders of Mongolia are to be found thousands of flocks of young dogs. The severe cold, with a mean temperature of 33° to 37° F., develops beautiful pelts. Concerning their further preparation, coloring, and the use of the flesh, see "Ausland."[9] In Greenland, where the caribou hunts are unprofitable, skins of seals and dogs are used in preference, the skin of the young dogs especially as a lining for winter boots; still it is very dear.[10] In Grisecke's time such skins were

[1] Burton and Cameron, To the Gold Coast, I, 335.

[2] The Discoveries of Prince Henry, p. 100.

[3] Finsch, Reise nach Westsibirien, p. 372.

[4] Kohl, Reise im Innern vom Russland und Polen, 206 et seq.

[5] Schweiz. Zeitsch. f. Jagd-u. Liebhaber, 1892. 183.

[6] Hamb. Correspondent von 2, 11, 1894.

[7] Zeitschr. f. allg. Erdk. N. F. XII, 211.

[8] Exner, China, p. 162.

[9] 1889, 337.

[10] Nordenskiöld, Grönland, p. 429; Natur. 1887, 536; von Becker, Arkt. Reise der Pandora, p. 16.

thrown away on account of their offensive smell.[1] With the Samoyeds the caps and the konitza (an article of female dress) are made of this fur.[2] Ravenstein[3] gives an account of this use by the Kiptchaks, Kraschennikow[4] by the Kamchatkans. In Kamchatka, as Steller has quoted from the yearbooks of Tag, a sort of cloth is made from dog's hair and different grasses.[5] The use to cover boxes in North America[6] and flasks on St. Kilda[7] is old. We find the custom widely spread of using the separate parts of the body of the dog for adornment, and, on the other hand, examples of expensive dog collars. In the latter connection K. Schumann,[8] the famous traveler, mentions that the Japanese, as has been related by the Arabs, made for favorite dogs, monkeys, etc , gold collars, thus anticipating the eccentricities of modern French and American ladies, such as Patti and others. The old Egyptians fitted their fine greyhounds with quite broad collars.[9] The fine dogs of the Bashilangi do not wear collars, but a band around the belly, similar to many Siberian draft dogs.[10] As an adornment and also as a means of deceptive decoration, the tails of many hairy animals are used. In Majorca part of the Sunday costume of every girl is a neat braid, not always genuine, as many fasten a cow's tail therein.[11] Before this, in ancient times, Indian women plaited the black hair of the yak under their own natural locks, *καὶ κοσμοῦνται μαλα ὡσαίως*.[12] Gustav Nachtigal saw in Wadai a Sklav woman who had fastened two heavy braids of sheep's hair under her own.[13] To the northward from the Victoria Nyanza, Baker met two men with horns on their heads and cow's tails instead of beards.[14] Many tribes of Indians comb the hair of the dead carefully, and in order to make the braid longer plait into it buffalo hair.[15] These analogies will suffice, and it is unnecessary to dwell upon those Australians who insert the bushy tail of the dingo dog into their beards in order to make them longer.[16] The Wahaha carry dog tails on their spears. The finger-long head of the spear is burned into the handle and held fast by the skin of such a tail drawn around it while still green.[17] The Parsi receive at puberty a girdle of

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[1] Greenland in Brewster's Encyclopedia.

[2] Zeitschr. f. allg. Erdk. N. F., X, 86; Erman, Reise um die Erde I, 701.

[3] The Russians on the Amoor, p. 317.

[4] Beschr. des L. Kamtschatka, p. 128.

[5] Zeitschr. f. allg. Erdk. N. F., XVI, 315.

[6] Natur, 1893, 161.

[7] Hamb. Echo, Beilage zu 17, 2, 1889.

[8] Marco Polo, p. 25.

[9] Ebers, Cicerone durch Aegypten, I, 161.

[10] Pogge in Mitth. d. afrikan. Ges. in Deutschland, IV, 248.

[11] Pagenstecker, Die Insel Mallorca, p. 135.

[12] Aelian.

[13] Sahara und Sudan, III, 80.

[14] Zeitschr. der Ges. f. Erdke., I, 103.

[15] Dodge, The Indians of the Far West, p. 114.

[16] Waitz, VI, 735, 736; Zeitschr. f. Ethn., VI, 278.

[17] Deutsche Kolonial-Zeitung, 1891, 162.

hair, which, according to the assertion of the Mesopotamian Jews, is plaited from dog's hair.[1] The Haidahs of British Columbia weave white dog's hair with other material, and on Puget Sound blankets are also made of it.[2]

The large white eyeteeth of the dog, worn singly in the ears or many together, also strung on a string, mingled with those of other carnivora, are widely used as an adornment, not only for men, but for women and girls; for example, as a breast ornament at Friedrich Wilhelms Haven in New Guinea, as necklaces and bracelets in the western part of the south coast of the British portion of that island;[3] near Cape Concordia such strings are more rare, the bones of *Abrus precatorius* being used instead.[4] On the Solomon Islands a traveler saw a magnificent necklace of 500 dog teeth, each of which was carefully bored through. Since only 2 teeth are here taken from each dog 250 dogs must have been required, most of which were natives of San Christoval, where the teeth are extracted from the living dogs without compunction.[5] In the southeastern portion of New Guinea all four eye teeth of these animals are taken, and with more reason than shells (cowries), used as money as they are in the Solomon Islands, Samoa, and other places; partly taking the place of our diamonds and other precious stones.[6] The Igorroto also wear necklaces and pendants of dogs' teeth.[7] These teeth are also used in New Guinea for weapons, and in the clubhouses there one may see many dog skulls hung up as decorations.[8] As in Java it is held to be disgraceful to have white teeth like those of the dog the people, as is well known, color their teeth and those of dogs are not used as ornaments.[9]

Schweinfurth saw in Africa necklaces of teeth of which there were several from the dog;[10] Junker saw similar ones among the Bari, and Schuver among the Berta.[11]

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[1] Zeitschr. f. allg. Erdk. N. F., V, 79.

[2] Bancroft, Native Races, I, 166, 215; Lelang, Fusang, p. 19; Lord, the Naturalist in Vancouver and British Columbia, II, 212–225. M. Boulet, the proprietor of a dog kennel in Évreux, gave to the former President of the French Republic a waistcoat made from the long hair of his "Marce;" Hamb. Fremdenblatt of 24, 11, 1888.

[3] Mitth. aus deutsch. Schutzgebieten, v. 12. Finsch, Samoafahrten, pp. 44, 89, 293; Rokoschny, Die Deutschen in d. Südsee, p. 55; Journal Geogr. Soc. London, 1876, 56; Peterm. Mitth., 1879, 277; Deutsche Geogr. Blätter, according to Alberti Ch. Lyne, New Guinea, p. 31.

[4] Finsch, loc. cit., p. 338.

[5] Natur, 1888, 139.

[6] Annalen des Wiener Hofmuseums, III, 4, 302; Ausland, 1884, 618; Deutsche Kolonialzeitung, VII, 105.

[7] Peterm. Ergänz.-Heft, No. 67, 25.

[8] Zeitschr. d. Ges. f. Erdk., 1877, 151; Proc. of the Queensland Branch of the Geogr. Soc. of Australia, III, 2, 67.

[9] Waitz, I, 366; Laplace, Voyage autour du monde, II, 463.

[10] Peterm. Mitth., 1871, 138; Zeitschr. d. Ges. f. Erdk., VI, 204.

[11] Peterm. Mitth., 1881, 86; Junkers Reisen, I, 283, 285, and Peterm. Ergänz.-Heft, No. 72, 65.

I may here briefly touch upon the use of the word dog as a term of reproach. In the Old Testament, by the Arabs, and especially by most Mohammedans, the word dog is an abusive epithet.[1] Among the Usbegs, while it is an impropriety to ask after a man's wife, to ask after his dog is a deadly insult, says Wood,[2] the epithet "dogseller" is the deepest of insults. In the fourth century B. C. Yâska was of the opinion that the name dog was sometimes applied to express contempt.[3] In Latin, canis, as an epithet always referred to some special trait of the dog (impudicity, cowardice, a snarling temper) and was not, as with us, an expression of exasperated contempt.[4] Must that not also have been the case in Halle in the fifteenth century, where it was the custom to give to men zoological names (Tyle-dog, Heinz-ape, Fritz-sheep, pigsty, etc.).[5] In a recent political election speech in Newcastle, Mr. Morley referred to the abusive use of the word "dog," declaring that he could not look upon it as an insult, for most dogs that he knew deserved to be placed higher than many men. The following sections will clearly show that many races take the same view.

It is a truly human trait to first recognize the worth of another after his death. This is exemplified by many of the hunting peoples of North America. The dog, the most faithful of the domestic animals, whose fidelity is recognized by the Koran, and who is therefore allowed to participate in the joys of the Mohammedan paradise, is cruelly treated by them while living, but when he dies and is transported to the happy hunting grounds they do honor to his bones. They will not offend his spirit because they will find him again in the after life.[6] Among the old Mexicans and Mayas he accompanied the dead in their passage to the other side;[7] among the mound-builders of Nashville, Tennessee,[8] and among the Eskimos[9] he was placed in the graves of young children who could not alone find their way to the spirit land. Dogs thus became the guardians of the threshold at the entrance to the nether world. According to the Zendavesta, certain dogs have the power of protecting departed spirits from the demons lying in wait for them on the perilous passage of the narrow bridge over the abyss of hell; and a dog is always led in funeral processions and made to look at the corpse.[10]

According to Synesius (fifth century), Cerberus held the position as

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[1] Hommel, Namen der Säugethiere bei den Südsemitischen Völkern, p. 311.

[2] Journey to the Source of the River Oxus, p. 143, and also Von Hellwald, Naturgeschichte des Menschen, II, 613.

[3] Max Müller, Vorlesungen über die Wissenschaft der Sprache, p. 374.

[4] Ausland, 1871, 170.

[5] G. F. Hertzberg, Gesch. d. Stadt Halle, I, 425.

[6] Waitz, III, 194.

[7] Bancroft, Native Races, II, 605; Zeitschr. f. Ethnologie, 1888, 20 et seq.; Congrès internat. des Americanistes, 1888, Berlin, 1890, p. 308 et seq., 321 et seq.

[8] Archiv Anthrop., III, 370; Bär, Der vorgeschichtliche Mensch, p. 474.

[9] Zeitschr. f. Ethnologie, 1872, 238; Nordenskiöld, Grönland, pp. 385, 474, 475.

[10] Verhandl. des 5 Geogr. Tages, p. 107; Forbes, A Naturalist's Wanderings in the Eastern Archipelago, p. 100, remark.

sentinel at the mouth of hell, and Dante represents him as keeping watch at the entrance to the third circle, where he torments the souls. "The Aztecs held the belief that the Techichi acted as a guide through the dark regions after death."[1] Luther asserts, in his "Table talk," that dogs also go to heaven. He firmly believed that he would again see his own little dog in the other world, and Klopstock's Messias (XVI, 260–333) has Elisama's dog enter heaven. The Countess Elizabeth Charlotte von Orleans said: "I am much pleased with what he (Leibnitz) has stated, that animals do not wholly perish. It comforts me very much about my dear little dog."[2] In German mythology the dog is the messenger of death,[3] and in Formosa when a dog howls the people have the priest come, for some member of the family is about to die.[4] Bastian[5] gives another view: God created the dog and assigned to him the duty of keeping watch against the serpent who betrays man. This is, therefore, the reason why, when one is about to die, the dog howls. In Borneo it is believed that he who laughs when a dog or a serpent crosses the path will be turned to stone.[6]

Black is recognized as a fateful color; black dogs are held to be the familiars of sorcerers; the evil one himself takes the form of a black dog (in Goethe's Faust). In the folk-tale of the wise Odin the black dog is the offspring of the devil; a great fear of the traveler on the Swedish heaths is that of meeting the Restless One with a couple of black, fire-spitting dogs. The heathen Samoyeds of the neighborhood of the Mezen offer to the devil either a reindeer or a black dog, who is drowned after sunset. The head is turned toward the west. These animals are offered also to the Tadepzii and Chechi, and the head of the victim is then thrown to its relatives; all the flesh is torn off from it, and the gnawed skull is placed on a pole opposite the idol.[7] The Lapps abuse their dogs, so necessary to them, with kicks, because they are held to be "the degenerate offspring of the wolf," who has intruded among men to work them harm. On this account, when these close relatives to the wolf have grown old they do not kill them, but fasten them to a tree until they have starved to death. For the same reason a dog must never be present at a marriage.[8] In the year 1702 the French soldiers who were defending Landau were firmly convinced that the black dog of their general was a familiar spirit of the devil, who

[1] Fr. A. Ober, Travels in Mexico, p. 320. The old inhabitants of the Cordilleras thought differently. Andrée Bresson says (Bolivia, p. 128): "In the burials of Arica, we find with the mummies the artificial eyes which the ancient Peruvians, actuated by a religious sentiment, placed near their dead to conduct them in the journey to the underworld; provisions for the route are also not forgotten."

[2] Zeitschr. des hist. Ver. f. Niedersachsen, 1884, 3.

[3] Zeitschr. f. Ethn., 1886, 82.

[4] Geogr. Proc. London, 1889, 233.

[5] Die Welt in ihren Spiegelungen, etc., p. 365.

[6] John, Life in the Forests of the Far East, p. 228.

[7] Zeitschr. f. allg. Erdk., N. F., VII, 62.

[8] Hogguer, Reise nach Lappland, p. 94.

personally drew up all plans of battle. Among the Esthonians black dogs, cats, moles, and cocks belong to that class of animals that must be sacrificed at the raising of the Kalevi treasure.[1] In Manchuria the evil spirit, or little black dog, is visible to the sorcerer alone.[2] The shamans, or medicine men, sacrifice a dog on great occasions for exorcism.[3] In Kamchatka a dog is also offered up to the evil spirit of the hills, the entrails are strewn around, and the body and hind legs hung on a long pole.[4] Of Phœnician origin was the worship of the goddess upon the promontory of Kolias near Athens, where, on the second day of the Thesmophorian festival, there were held at night orgies during which dogs were offered up, a custom which fully indicates its oriental origin.[5] In West Timor, as a declaration of war, the head of a black dog is thrown into the territory of the enemy.[6]

The dog was worshiped and appeased as a god by many peoples, as in America among the ancient Peruvians of Xauxa and Huanca, where priests blew upon the skeletonized heads of dogs. In Cuzco, the blood of black dogs was smeared over the countenances of the idols, their hearts and lungs were used in augury; the ears of dogs used at a burial were cut off.[7] Similar offerings were known earlier in Yucatan.[8] In Africa, the Baghirmi, natives of Gabberi, also sacrifice dogs.[9] At ancient Byblus, in Asia, the dog was sacred to Mars. On the Lykos River, in Syria, stood a hollow idol of a dog which sounded as the wind blew threw it, but on the approach of an enemy barked, in tones audible as far as Cyprus. The dog is also honored by many families of the Ansurii. Zoroaster also makes this animal sacred and it is highly honored by the Kolis.[10] In Sikkim, the household gods of the Metch are distorted figures of a god often pictured as riding on a dog.[11] In Japan, dogs are numerous because they are held as sacred. These dogs are often buried so that only the head remains free. Before the nose of the dog is placed dainty food. After this Tantalus-like torture, the head is cut off shortly before death from starvation, and made into the mysterious box of the priest.[12] That a long time ago

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[1] Archiv Anthrop., X, 89.

[2] Journal Geogr. Soc. of London, 1872, 173.

[3] Prschewalsky, Reisen nach Thibet, p. 150.

[4] Kennan, Tent Life in Siberia, p. 113.

[5] Oberhummer, Phoenizier in Akarnanien, p. 60; Movers, Die Phoeniz. I, 404 et seq.; Hundeopfer bei Phoeniz. Holm, I, 89, 374.

[6] Deutsche Geogr. Blatter, X, 229.

[7] Humboldt, Ansicht d. Natur, 1849, I, 135, 460; Waitz, IV, 453; Kolenati Reiseerinnerungen, p. 86; Journ. Geogr. Soc. London, II, 200; Steffen, Landwirthschaft bei d. altamer. Völkern, p. 29; Philippi in Festschr. d. Ver. f. Naturkunde, Cassel, 1886, 3; Zeitschr. f. Ethnologie, 1888, 20.

[8] Waitz, IV, 309.

[9] H. Barth's Reise, III, 571.

[10] Ritter, Erdkunde, XVII, 1, 62, 510; Bastian, Geogr. u. Ethnolog. Bilder, p. 224.

[11] Deutsche Rundschau f. Geogr. u. Stat., X, 341.

[12] Zeitschr. f. allg. Erdk., N. F., IV, 428; Zeitschr. f. Ethn., 1877, 335.

offerings of dogs were made at Sakhalin, was determined by Poljakow from discoveries at old places of sacrifice, where, among countless other bones, ten toothless skulls of dogs were also found.[1] The Koriaks likewise, in order to insure good fishing, made offerings of dogs, and, indeed, of the best, because the god commanded it; these were simply hanged upon trees. It cost Major Abase much trouble to make them understand that the worst dogs would answer the same purpose.[2] In northern Siam, between Scwegun and Hlaingbwe, the Karens propitiate the spirits by suspending the carcass of a dog from an improvised altar of bamboo.[3] In Cambodia, dog's teeth drive away ghosts, and in Sumatran traditions dogs play significant parts.[4] In the Celebes, the people sacrifice dogs, because through such an offering the ground becomes more fruitful.[5]

In Australasia, at Samoa, dogs and some birds are consecrated to the greater gods; at the Solomon Islands, together with other skulls, those of dogs are hung in considerable numbers in each village.[6] In New Guinea, at the Kaiserin-Augusta River, a dog was killed as a sign of friendship for the Europeans, and in New Zealand Forbes found, in an undisturbed cave, the carved figure of a Maori dog, which was contemporaneous with the moa.[7]

Among the ancients I will only mention that the Romans offered up to their gods yearly upon their altars a considerable quantity of dog's flesh, and that in the temple of Zeus Adranos 1,000 dogs were used as guards.[8] I might here add a few instances which show that dogs are also regarded with significance in Christendom, especially during the Christmas season. As Branchion was following a stag with dogs, the animal took refuge in the cave of a hermit, and the hunters and dogs knelt in awe before the cross. In France it is believed that during the Christmas midnight mass the animals kneel in their stalls, but it is very imprudent to watch them, because they will all attack you. In Poland, at this season, the young girls go out into the yard and listen for the barking of the dogs; from the side where a dog barks a future husband will come. In the Christmas matins of Stralsund, an eyewitness of the sixteenth century reports that quite different behavior occurred; the house of God was made a romping place for the greatest misconduct. Young men sat in women's clothes on the women's chairs, others were clothed like shepherds, took dogs and goats along

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[1] Reise nach-Sachalin, p. 42.

[2] Knox, Overland through Asia, p. 85.

[3] Mitth. Geogr. Ges. Jena, H. 4, 245.

[4] Ausland, 1886, 113, v. Brenner, Besuch bei d. Kannibalen S., p. 199.

[5] Temminck, Coup d'oeil, etc., III, 64.

[6] George Turner, Samoa, p. 113; H. H. Romilly, The Western Pacific and New Guinea, p. 74.

[7] Deutsche Geogr. Blätter IX, 349; Revue Coloniale Internat., IV, 265; Globus, 1891, I, 64.

[8] Deutsche Jäger-Z. XIII, 1059; Hartwig, Aus Sicilien, I, 46.

with them, ran up and down the church with these beasts, screaming and rolling over each other on the floor.[1] Among the country people of India a similar custom prevails, where at a birth festival boys and girls enact a scene of childbirth, the newborn child being represented by a young dog.[2] Dogs also understand how to distinguish between various religions. In a Chinese writing that treats of the preservation of the purity of the Chinese customs it is said, "The corruption of the foreign devils (i. e., the Roman Catholic Christians) is so great that even pigs and dogs refuse to eat their flesh."[3]

Many people suppose that if dogs are allowed to gnaw the bones of animals pursued in the chase or used for sacrifice the hunt or the offering will prove ineffectual. Among the Eskimos the dogs must not gnaw seal bones while the seal hunt is going on.[4] The Metschers and Mordwinians, the oldest inhabitants of the Tambol Government, after a meal instituted in honor of the war gods, throw the remaining bones into the water so that the dogs may not eat them.[5] When the dog fails in his special quality, watchfulness, he deserves punishment "even to the third and fourth generation." The Romans gave to their dogs every year a sound flogging because their forefathers slept during the attack on the capitol by the Gauls while the geese gave the alarm for which they have received so much honor. This custom was even surpassed in Paris during the time of Louis XIV, when annually, on a set day, many dogs and cats were buried by the magistrates with festival ceremonies on the Place du Grève.

In Germany, several centuries ago, the killing of dogs was allowed "to flayers and knackers, also to doctors and students of medicine, that they might better learn the human body; further, to apothecaries, that they might thus obtain medicines."[6] Elsewhere, also, such remedies have been found efficacious. The Tchuktches sometimes kill a dog in order to anoint and heal the sick with its fat and blood.[7] As a remedy for *Filaria medinensis* natives in Kordofan drink beer (merissa) in which dog's excrement has been placed.[8] The fetich Koro, a dog with two heads, is considered in Inshono as very powerful against disease.[9] Through dogs may diseases also be occasioned, as, for example, among the Nubians, where the taking in of a dog's breath may cause "the worst kind of internal disorders."[10] * * * The mandrake root, well known in ancient German and Roman times, appears also with all

[1] Lecky, History of European Morals, II, 135; Deutsche Jäger-Z. XX, 383.
[2] Zeitschr. f. Ethn. V, 184.
[3] Isabella L. Bird, The Golden Chersonese, p. 69.
[4] Klutschak, Als Eskimo unter E., p. 123. Neumayer, Die deutsch. Expedit., II, 26.
[5] Ausland, 1884, 29.
[6] Zeitschr. f. deutsche Kulturgesche. N. F. V., 56 et seq.
[7] Sauer, Reise in d. nordl. Gegend von russ. Asien, p. 236.
[8] Marno, Reise in das Gebiet des blau. u. weiss. Nils, p. 405.
[9] Zeitschr. f. Ethn., VI, 9.
[10] Schweinfurth, Im Herz. v. Afrika, II, 344.

its power in the country of the upper Nile, where its possession gives the greatest good fortune to man. When fastened to the tail of a dog, to be torn up by the roots, it cries.[1] One of the most remarkable outgrowths of superstition is the *σκυλογαμος;* that is to say, the holding of the so-called dog's marriage at Cyprus, as an approved means for curing the bite of a mad dog. If anyone was bitten in this way, he must, exactly forty days thereafter, celebrate a dog's marriage, at which he must heartily eat, drink, and dance; he must not sleep during the next night, and the poison of the rabies will pass off by transpiration.[2] In the tradition of the sea of quicksilver the metal can be collected only by means of dogs-skins sewed together.[3] Concerning the dog in Persian mythology, compare Gerlach, and concerning the holy fire of the Gebers in the Jezd oasis, in which were 72 to 75 different materials, among which a widow and a dog, see Ritter.[4]

The portents of dogs in folklore are treated at length in "Ausland,"[5] but to what is there said I may add a few remarks. The Mbocavies (Pampas) think that certain of the stars are an ostrich that is pursued by the heavenly dogs. The moon is a man, and when it suffers eclipse its entrails are torn out by dogs.[6] In Mongolian mythology it is said that the moon in the shape of a yellow dog has licked his own chops.[7] In the time reckoning of many peoples the dog also plays a part. "The Cambodians, like all peoples who have taken from China the elements of their calendar, use for designation of time a duodenary cycle, each year of which bears the name of an animal—chachien."[8] So also in Siam, Annam, among the eastern Khirghises, etc.[9] Among the converted Indians of Istlavacan not only is a month called after the dog, but also a day in each month.[10]

Hunters and shepherds among the most different peoples know that their dogs understand exactly their speech and gestures, and so do those that busy themselves much with dogs,[11] and conversely the masters understand the various notes of the voices of the dogs that have become much modified by the contact with civilization and under the training of man. On that account the inhabitants of the Gold Coast formerly believed that European dogs could talk, and in Unyoro the tradition is current that dogs were once endowed with speech.[12] That

[1] Friedländer, Sittengesch. Roms I, 436. Marno loc. cit., p. 241.

[2] Ohnefalsch-Richter in Unsere Zeit 1884, H. 3, p. 365.

[3] Haxthausen, Transkaukasien, p. 323.

[4] Gerlach, Seelenthätigkeit, p. 2. Ritter, in Zeitschr. f. allg. Erdk. V, 79.

[5] 1891, 874.

[6] Waitz, III, 472.

[7] Zeitschr. f. Ethn., VI (107).

[8] Lagrée et Garnier, Voyage d'Explorat. en Indochine, I, 93.

[9] Ed. Hildebrandt, Reise um die Erde, 1873, p. 160; Giglioli, Viaggio intorno al globo, p. 319; Ritter, Erdk., II, 1124; Prschewalsky, Reisen in der Mongolei, p. 55.

[10] Waitz, IV, 175; v. Scherzer, Aus Natur- und Volksleben im trop. Amerika, p. 175.

[11] Andr. Stengel, Die Anfänge der Sprache, p. 18; Bastian, Sprachvergl. Studien, p. 18.

[12] Histoire générale des voyages, X, 115; Côte d'Or, according to Arthus, p. 80; Peterm. Mitth., 1879, 391.

the association of shepherds and dogs in Egypt alone reaches back for thousands of years, we see from the sceptre of the Pharaohs, a long shepherd's staff whose crook has the form of the head of an animal, indeed a very well-designed head of a dog. Wilkinson saw similar staffs among the Egyptian peasants of to-day, as did also Virchow and Schliemann at Epidauris.[1]

In Yule's masterly work[2] we read: "The doghead feature is at least as old as Ctesias. The story originated, I imagine, in the disgust with which allophylian types of countenance are regarded, kindred to the feeling which makes the Hindoos and other eastern nations represent the aborigines whom they superseded as demons. The Cubans described the Caribs to Columbus as maneaters with dogs' muzzles, and the old Danes had tales of Cynocephali in Finland. Ibn Batuta describes an Indo-Chinese tribe on the coast of Arakan or Pegu as having dogs' mouths, but says the women were beautiful. Trio Jordanus has heard the same of the dog-headed islanders. And one form of the story, found, strange to say, in China and diffused over Ethiopia, represents the males as actual dogs and represents the females as women. Oddly, too, Père Barbe tells us that a tradition of the Nicobar people themselves represents as of canine descent, but on the female side! The like tale, in early Portuguese days, was told by the Peguans, viz., that they sprang from a dog and a Chinese woman. It is mentioned by Camoens (10, 122). Note, however, that in Colonel Man's notice of the wilder part of the Nicobar people the projecting canine teeth are spoken of." To these words I will add the following notes: Forbes[3] speaks of the transformation of a dog into a man; according to Colquhoun,[4] a dog married a "daughter of Yao," and Robert Hartman[5] discusses the tradition that in Dschur lo wate (woman town) there were only women, and these consorted with dogs.

On the island of Hainan the aborigines, the Li-tse, descended from dogs, and therefore yet have tails as appendages.[6] Radloff[7] speaks of the origin of the Khirgises from dogs. The Ainos trace their derivation from the offspring of a woman and a dog.[8] Also in America many stocks derive their own origin from dogs—for example, the Chuchacas, the Kadiaks, the Chippeways, the Dog-rib Indians.[9] According to Boas, this came to pass in the latter case very easily. A woman driven from her tribe married a dog, bore to him six dogs, and once surprised them

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[1] Zeitschr. f. Ethn., XX (391).

[2] The Book of Marco Polo, II, 252.

[3] Eastern Archipelago, p. 100.

[4] Amongst the Shans, p. 45.

[5] Zeitschr. f. Ethn., II, 138.

[6] Ausland, 1884, 916.

[7] Peterm. Mitth., 1864, 165.

[8] Zeitschr. f. Ethn., XIV (180); cf. Bird, Unbeaten Tracks in Japan, II, 33; Ausland, 1888, 842.

[9] Zeitschr. f. Ethn., VI, 272; Zeitschr. d. Ges. f. Erdk. Berlin, II, 433; Waitz, III, 191; Bancroft, Native Races, I, 118; Peterm. Mitth., 1891, Literatur, p. 102.

with their skins off, at which time they were children. She craftily took their skins away, and they consequently became men and the ancestors of these Indians. Bastian[1] informs us that men, on account of evil deeds, may lose their voices and must for punishment bark like dogs. In conclusion, I will give only two more examples. That the souls of men may find homes in the bodies of dogs is held at Tongking[2] and at Africa, where, among the Baschilange, according to Pogge, the faith prevails. Therefore they call those who eat no dog's flesh "Muschilambus." Whether this is because of any veneration to the dog he does not know. Kalambo, however, has all dogs killed because they are magical beings.[3]

For a number of years past I have been working on a book which is to contain a collection of the names given to mammals by all peoples, and it will be readily understood that in this collection the designations for the widely distributed dog surpass all others in number. Let us see what deductions can be drawn from the names given to dogs by savages in the four quarters of the globe.

Among the African names for the dog there is one that is also used for animals in general; among others there are several that are used in one and the same tribe for swine. This favors the view that the earliest dogs among them were not used either for the chase or as guardians, but, like swine, for food, perhaps as far back as that epoch when the northern part of Africa had a different conformation, together with a different flora and fauna.

In North America a comparison of the words for wolf and dog show us that, as was also known from zoological reasons, the dog distributed from north to south was partly derived from the *Canis latrans* by the somewhat active intercourse between the Indian tribes of the Northwest and the peoples of northeastern Asia, and also that at an early period the dog of the Tchuktches and Kamchatkans came over, for the Kamchatkan name for dog is also found in America. When later the European horse was brought on he frequently received the name of some species of deer; but, as he soon became indispensable, he sometimes received the same name as the only domestic animal they had hitherto had; so in Dakota the mystical word for horse is "*schanka-wankan*," the holy or spirit dog.

In South America, as in Africa, we sometimes find the same name used for dog and pig; occasionally the same for dog and beast of prey. The bare word *tchinu* (dog) is the same as the Botocudo *tchine* (animal), also *thücke utschiaghanti* among the Miranhas; in the same way the modern Greeks call the horse generally the animal, the Italians call sheep *pecora*, on the Romagna *pigura;* the Greeks of Thira designate all beasts of burden *κτῆμα*, in Syra irregularly *τὸ κτηνό*. The age of the South

[1] Zur Kenntnis Hawaiis S., 83.

[2] Zeitschr. f. allg. Erdk., I, 108.

[3] Mitth. d. afrikan. Ges. in Deutschland, IV, 255; Wissmann, Durchquerung Afr., p. 128.

American aborigines can not be measured by means of historical data, but may, perhaps, be estimated in another way. The meal industry is without doubt the most significant feature of the civilization of these tribes to whom the use of milk and its products is entirely unknown. The Old World used only innocuous grain food plants, increasing them by cultivation and forming from their products meal and bread. In South America, on the contrary, a very poisonous, quickly fatal plant is first deprived of its poison, and the porridge then made from it is rendered palatable by the addition of the juice from the little Limonia, the bark of *Dicypellium caryophyllatum*, ants, or honey. The customs of changing the fruit of the *Gulielma speciosa*, of producing yellow parrot feathers by means of frog's blood (among the Munderucus), and many similar ones that are widely spread also point to an old civilization with which many races of dogs may have been contemporaneous.

In southeastern Asia we meet with a word for the dog that means animals in general; in another case his designation is the same as that for the horse, the pig, and carnivorous animals, and the same obtains in the Ural-altaic, Slavic, and Germanic tongues, where the designations for dog, wolf, and fox have often the same origin. Three thousand years ago the Chinese called all the nomads of the west dogs, and the word dog in Turko-Tatar was derived from "*et*" (low, base) or from "*kurt*" (greedy animal). The Turanian ideogram for dog is *ur-ku*, which, according to Halevy, is derived from *ur* (flesh-eating) and *ku* (domestic). It is striking that the root words for dog and bear never agree, while those for dog and the smaller carnivoræ sometimes do so.

The statement of Leland, "all ignorant and unscientific people give to unnamed animals the name of some creature with which they are familiar," holds good for the savages of Australia and Oceanica. Many words for dog, such as *keru*, signify also animals in general; so, also, *keru kejerik*, the rat animal, i. e., cat (Museum Godeffroy, I, 43); others signify also pig—for example, buga, brooas (Pott, Etymology. Faschungen, II, 1, 138). Kittlitz (II, 8) remarks that after one had once seen a pig every large animál, even the cat, was called *cochon*, just as the Jakuts use the Mongolian word for pig (*chachai*) as a designation for the leopard. At Queen Charlotte Sound the natives called all the quadrupeds that Cook had with him dogs. (Voyage toward the South Pole, I, 125.) As the sailors in calling the dog toward them said "come here," so the inhabitants of Mortlock Isla d afterwards called the dog "comehere."

In the Verdidad, the oldest and most genuine portion of Zendavesta, it is said: "The world is maintained by the intelligence of the dog," and Brehm adds to this: "We can not conceive of savage man without the dog; still less can we imagine the educated and cultivated inhabitants of the thickly populated parts of the earth." The dog is a part of man himself. He is, as Fr. Cuvier expresses it, the most remarkable, complete, and useful acquisition which man has ever made.

THE LIFE AND WORKS OF BROWN-SÉQUARD.[1]

By M. BERTHELOT.

Geber, the Arabian philosopher and chemist, asserts that the perfection of a being depends upon an exact equilibrium among its elements. Whenever that state of equilibrium is obtained, he says, the being becomes immortal, because there is then a complete compensation between its opposing elements and nature. Whatever may be thought of such reasoning, ideas and definitions of this kind correspond but little with the conditions that affect genius in art and science. In fact power and beauty generally are the result of the exaltation of certain qualities developed with an unusual intensity; this constitutes the true originality of genius, and all compensation between contrary aptitudes results in a certain mediocrity.

These truths have rarely found a more striking application than in the career of Brown-Séquard. He possessed qualities of imagination and of originality characteristic of great discoverers, rather than those habits of precision, accuracy, and application that belong to scientists of repute in their work, scientists that are perhaps more esteemed in the academies because they have fewer imperfections. Still, let us not forget that it is the inventive minds that keep humanity going.

Brown-Séquard was an inventor, and some of his fundamental ideas, thought to be strange and almost senseless at the time they were expressed, in the crude state in which he frequently left them, have yet shown an originality as marked, perhaps, as those of Pasteur or of Claude Bernard. Brown-Séquard left a profound mark on the biological field because he had a very high ideal of science, an ideal that he pursued in spite of all obstacles with a passionate devotion, sacrificing to it the idols ordinarily worshiped by man—money, position, and honors. In his business affairs there was the same instability, the same want of balance as in his intellectual career, and he passed an existence as wandering and agitated as that of a scientist of the sixteenth century. He spent his life between two races, the French and the Anglo Saxon, to both of which he belonged by family connections, traversing the routes of the

[1]A paper read at the annual public session of the Académie des Sciences, of Paris, December 19, 1898. Translated from the Revue Scientifique, fourth series, Vol. X, pp. 801–812.

world, from the Indian Ocean, where he was born, to the coasts of Europe and America; sometimes an experimenter, sometimes a consulting physician, sometimes a scientific journalist, and sometimes a professor; at Paris, at London, at Dublin, at New York, at Boston, until the time when he found in his later years a resting place and the crown of his career in our old but always youthful College of France, always an asylum for original intellects, and in our Academy of Sciences, a final consecration of scientific work.

Such is the man whose life and work I am about to try to sketch.

Charles Édouard Brown-Séquard was born April 8, 1817, at Port-Louis (Mauritius) of an American father, Brown, of Philadelphia, and a French mother, who was a Mlle. Séquard, of Provençal origin. His father, a captain in the merchant marine, went to sea with his vessel some months before the birth of his son, and was never heard of again. Brown's lot was in this respect like that of E. Rénan, who also lost his father under similar circumstances. Our scientist bore, in his physical frame as in his intellectual character, the traces of this double origin, modified by the climate of his birthplace. From his mother he inherited that southern vivacity and sympathetic character that attracted so many to him, while from his father he derived that adventurous boldness which he carried into his experiments, and also that ability to promptly change the surroundings of his life and to work without cessation during the constant shifting about of an adventurous career. The tropical land where he was born endowed him with the physical characteristics of the Indian creole. Formerly a French colony, it was torn away from its native country by the disasters of 1814, because it was a naval station of the first rank, being the base of the bold expeditions conducted by Dupleix and La Bourdonnais, in the eighteenth century.

Therefore, England, who hastens to seize every island, every cape, and every strait that controls the sea, did not neglect to possess herself of Mauritius at the time of our misfortune. The population has, however, even to the present day, preserved a certain attachment for the country from which it sprang.

When Brown-Séquard was born Mauritius was no longer French territory, and this was the reason why, when after a wandering existence, he wished at the decline of his life to settle finally in France, it was necessary for him to become naturalized. Still his native tongue was French, and when he made his first visit to the United States he was obliged to learn English, which he did during the voyage.

In the midst of privation and poverty his mother raised him with a tenderness of which he always preserved the most lively remembrance. She lived by the work of her needle, employing an aged negro to sell her embroidery. Thus it was that our future colleague was initiated into the severe struggle for existence, an initiation that tempers the spirit of those that can submit to it without shrinking. It is well to detail it here in order that we may understand the course which Brown pursued for a long time and the incomplete character of his works.

At 15 years of age he became a clerk in a colonial provision store, which was also, as in Italy, a place of rendezvous and gossip, so that the young man was in contact not only with the laboring people but also with the cultivated residents of the neighborhood. He showed the influence of the latter by writing poetry, romances, and plays, a beginning often made by those who have not received a regular education. In reality these attempts are about equivalent to the scholastic exercises produced by the rhetoricians and philosophers of our graduating classes.

At 20 years of age Brown set out with his mother for Paris, then the ideal center of attraction for natives of Mauritius. Immediately on his arrival in 1838, counting innocently on his literary talents for support, he presented his works to Charles Nodier, who hastened to enlighten him as to their true merit by saying, "In order to live you must take up some regular business, my friend."

Claude Bernard had in a similar manner begun by writing a tragedy. But without being rich he was not so poor as Brown-Séquard. The latter, also like Bernard, followed the advice given him and decided that he would become a physician, a profession for which he had hitherto shown no predilection.

This profession did but little toward satisfying his immediate wants, for it could bring in nothing until after long years of apprenticeship. Besides, Brown-Séquard had no preparation for it whatever; preliminary scientific knowledge was wanting as well as material resources. Special qualifications were also needed, but of these there was fortunately no lack.

The mother and son leased rooms in the rue Férou near St. Sulpice, and there gave board and lodging to students from Mauritius who were more fortunate than they.

These little groups of foreigners, clustering around their compatriots, are common in Paris; it is greatly to be regretted that the administration has of late years made constant efforts to discourage them and to get them attached to faculties in the provinces, where they will not acquire so readily a hearty sympathy with our national life.

In the meantime Brown-Séquard was at work trying to amend, or rather to completely renew, his education. He prepared at the same time his medical examinations and two baccalaureate courses in letters and sciences; for it had not yet pleased the authorities to prolong the duration of the courses which are now retarded by a series of barriers regularly spaced off.

Our future colleague filled a double office, that of pupil in the laboratory of Martin Magron and that of tutor, transmitting the knowledge that he had just acquired to his less active and less intelligent comrades. This is a profession in which more than one of us has commenced his career, thus finding, as did Brown-Séquard, the pecuniary resources necessary for obtaining an education. It should not be supposed that these conditions are absolutely unfavorable; on the contrary, by teaching one is forced to learn more thoroughly what is taught; some author, whose name I do not remember, has said that in order to teach it is necessary to know a subject twice over. A teacher must certainly apply himself to think out and assimilate his subject in a way not often accomplished by the young student who pays scanty attention to the lesson, listening with a distracted mind and perhaps never thinking of it again.

It was by contact with these Parisian masters that there came to Brown-Séquard the revelation of his true vocation, which had hitherto remained obscure. While reproducing the experiments of others in the laboratory of Martin Magron, he conceived the idea of experimenting on his own account; his passion for physiology burst forth and assisted to sustain him in the midst of painful trials while he was entering upon a life of difficulties. He was, in fact, soon subjected to both personal and family troubles.

A dissecting wound, an accident still too frequent among students, made him ill for long months. Scarcely had he recovered when he lost his mother, his devoted companion and support. Brown-Séquard had a peculiarly sensitive and affectionate nature, which often made him unhappy during the course of his life. Prostrated by this unexpected stroke, carried away by an irresistible influence, and semidelirious, he quitted Paris and embarked for his native land. Hardly arrived there, more reduced in material resources than ever, and finding it impossible to renew them in so restricted a sphere, he obtained the aid of a friend to return to Paris.

Friends were never wanting to Brown-Séquard. Like all loving natures he always received keen and affectionate sympathy.

He then returned to Paris, poorer than ever, to finish his medical studies, working in a poor chamber and nourished sometimes on only dry bread and water; without fire in the dead of winter, living helter-skelter with guinea pigs and rabbits, the subjects of his experiments, who were henceforth to be his companions up to his very last moments, for half a century.

He graduated in medicine in 1840, publishing in his thesis a preliminary sketch of his researches on the nervous system.

It should not, however, be supposed that Brown was always unhappy; as is usual in youth he lived upon imagination and hope, exalted by his discoveries. He often in after life referred to these first years with affectionate remembrance.

This young man, so industrious and zealous, could not long fail to receive aid from those around him—aid from the young scientists and artists of his own age, aid also from scientists who had already become famous. If we should accuse some of the latter of being selfish and jealous it would be an accusation which, as all this company knows, it would be very unjust to make general. Among the devotees of science there are many who are happy to aid and encourage beginners, to sustain them, and to hand to them in turn the torch of science, which it is our duty, our honor, and our pleasure to keep burning still more brilliantly during the next generation.

In this manner Brown-Séquard lived until about 1848. At this epoch, so fertile in disclosures and in quickly-blighted hopes, he found himself placed, because of his experimental work, in relation with the Society of Biology, founded during that very year, and of which he was later to become one of the principal pillars of support.

The Society of Biology had just been founded at the instance of certain young men, such as Charles Robin, Claude Bernard, Follin, and others whose names have become well known. Brown-Séquard was one of its first four secretaries. It was and has not ceased to be an excellent forum for the study and discussion of problems of natural science, a forum less solemn than those of the academies, the discussions being more friendly, not being exposed in the same degree to disturbing vanities and personalities unduly excited by a sometimes excessive publicity. There is found there a sincerity and consequently a greater certitude in the demonstrations as well as the concurrence and collaboration of comrades of the same age not yet disunited by the rivalries of a career.

On the other hand, resources of all kinds were scanty at the Society of Biology. Science, especially at that time, furnished but little to beginners. Since then the Republic has increased these resources, especially in the form of those scholarships for superior instruction, which have in recent times been unjustly attacked by those who have narrow views, and who are perhaps actuated by jealousy of progressive methods.

While the Society of Biology did not furnish the same resources as we have at our command to-day, it nevertheless aided, even from the first, the young scientists who crowded to its ranks, attracted both by the confraternity of scientific work and by the good will of the first president, Rayer. Rayer was a man of experience and judgment rather than of originality; a clever man who had by his merit attained a good position, both from a pecuniary and a scientific point of view. This did not prevent him from remembering that in his youth he had suffered from the religious and philosophical intolerance of the Restoration, which had barred him from a teaching career, and he took pleasure in protecting young scientists and in aiding them by his influence, which was great, and which was to become much greater by reason of the repute that attached to him because of professional medical services rendered to prominent and powerful people. Claude Bernard, Charles Robin, and others also, among whom I have the honor to count myself, have received from Rayer assistance in their careers which they have never forgotten.

Rayer thus gave to Brown-Séquard his first opportunities for work; he interested himself in him and confided to his care certain patients whom he thought ought to be treated by galvanism.

The next year, in 1849, during that deadly epidemic of cholera, which left a profound impression on the minds of the students and doctors of my time who were called to treat the sick and dying, Brown-Séquard was appointed as assistant physician at the military hospital of Gros-Caillou. It was a dangerous post, requiring devotion to duty. Brown never drew back on such occasions.

Still his means of existence continued to be uncertain. In 1852 he found hinself at the end of his resources, and his republican opinions hardly permitted him to hope for any official support. He embarked for New York on a sailing vessel. He was ignorant of the language of the country where he was going to seek his fortune, but he smilingly said that he counted on the length of the voyage for learning English and on his profession for subsistence when he had once arrived in the United States. He showed at this time that mixture of almost childish want of foresight and self-confidence that characterized his entire life; tossed about incessantly from fortune to poverty, always rescued before reaching the last extremity and always recovering himself by his own energy.

Thus it was that he commenced that irregular career that led him so many times from France to England and to America, and from America to England and to France, attracted on the one hand by the desire for a life in Paris, the only place where his scientific instincts were completely satisfied, and on the other by his Anglo-American traditions that led him to seek for a living in New York or London, where applied science was more generously compensated. He crossed the ocean in this way more than sixty times in the course of a half century.

This existence of a scientist wandering from country to country becomes more and more rare and difficult. During the sixteenth century it was almost the usual method of life. As the new spirit of the Renaissance found but little encouragement in the old scholastic universities, scientists and artists were then in the habit of wandering between France, Italy, Germany, and sometimes England, seeking the protection, too often capricious, of princes and sovereigns. In the seventeenth century Louis XIV called to France Cassini, Huyghens, and many others, some of whom, indeed, founded dynasties there.

The eighteenth century, with its ideas concerning the moral and intellectual unity of the human race, was favorable to this wandering habit. Even in our own days we have seen that in the early part of the present century it was kept up between France, Italy, and Germany, as well as between Germany, England, and Russia. It would be easy to cite numerous examples of this, but since the wars of the last forty years that have established the great European States these powers have become more jealous of each other; each has tried to preserve more and more the advantages of its own State for its own citizens. This tendency to exclusion has begun to affect even the United States. The life of a wandering scientist, such as Brown-Séquard, has therefore become quite difficult. Perhaps, indeed, it would not have been possible, even in his time, had he not possessed special qualities derived from his racial origin.

Although we can thus easily explain the national exclusiveness of the present day, we may perhaps in certain respects see cause to regret it; for the exchange of ideas and conceptions between peoples is more easily effected by means of persons than by books, and this exchange is indispensable for the general diffusion of knowledge and culture.

Hardly had Brown-Séquard landed at New York when he was obliged to give lessons in French to support himself. He made the acquaintance of some of the distinguished physicians of the city who had attended at Paris the lectures of Magendie, Andral, and Bouillaud. They obtained for him the post of teacher of experimental physiology in one of the American medical schools. At the present time a young Parisian physician would hardly find such resources in New York. In the first place, because scientific culture has remarkably developed in America during the past half century, and the Americans find among themselves the necessary teachers; but also because we no longer, to the great damage of French influence, give the same welcome to foreign students. Too frequently, repulsed by us, they go to complete their education in Germany. Let us hope that our University of Paris will pursue a more enlightened course and repair the sad mistakes into which narrow-minded persons have led her.

In 1853 Brown Séquard was in America and led there a very unsettled life. In order to support himself he resorted to obstetric practice at $5 a case, and assisted in the preparation of a treatise on obstetrics. In the meantime he married, espousing Miss Fletcher, niece of Daniel Webster, the celebrated orator, and had by her a son, recently deceased, who gave his father but little satisfaction. Brown-Séquard returned to France during the summer, without, however, finding there any more solid means of support. Patients did not care for a physician so unsettled in his habits. He would not, however, abandon science, which was always the principal subject of his thoughts. It was, indeed, at this time that he published, in the Philosophical Medical Examiner, his first paper on experimental epilepsy. Still adventurous and unsettled, he returned to the United States, to leave again in 1854, in order to visit Mauritius, his native island. There he chanced upon an epidemic of cholera, which was decimating the population. Physicians were needed. Brown Séquard was put in charge of a hospital and various relief establishments. The treatment he adopted, founded upon the use of opium, was in accordance with the practice of the period. The principal fruit of his services was a gold medal, struck by order of the municipality of Port Louis. At the end of the year he returned to the United States, where he received the appointment of professor of physiology in the University of Richmond, Virginia, and began his course in 1855.

He seemed then to have a secure position, which would enable him to live and to devote himself to original researches. This was, however, a delusion. The directors and the pupils of the university required didactic, elementary knowledge only, to prepare the pupils to answer examination questions. As to original researches, neither the one nor the other cared anything about them. Besides, there were already coming up in Virginia certain problems of a more extended political and social character, relating to slavery, an institution thought by the Southern States to be essential. Already there was beginning that fermentation which culminated a few years later in the war of secession. Now Brown-Séquard was too much attached to the humanitarian ideas of the eighteenth century and of the French revolution to hesitate. His social position in Richmond became unpleasant. It was practicable for him to make a change he had in view, as he had been able to acquire some income in the practice of medicine. Accordingly, instead of pursuing in the United States the career now open before him, he took advantage of the small sum he had accumulated by economy and hastened to Paris, the center of attraction to which he was always drawn.

It was at this period that I saw him for the first time, at the end of 1855, in the sympathetic circle of the Society of Biology. He was then 38 years of age. I have still before me a vision of that original face, delicate and kindly, embrowned by the climate of his native island; those keen and gentle eyes, always in restless motion, animated at once with an affectionate regard for the friends of science and by an unceasing and ever-watchful curiosity, which led him to search out her secrets, and also by some inexplicable feeling of timidity, which doubtless caused his inability to manage his own affairs.

His personal devotion to science was unbounded, and led him more than once to make experiments that might endanger his health. Thus he repeated in his own person the experiments that Spallanzani had made upon ravens, that of collecting gastric juice by means of a sponge attached to a string, swallowing the former and then withdrawing it from his stomach charged with the precious liquid. The following story, even more striking, is related of him.

In 1851 he was making researches upon red and dark blood. He injected into the arm of an executed criminal, thirteen hours after decapitation, 250 grams of his own blood, obtained by opening a vein.

In 1855 he set up in the rue St. Jacques a physiological laboratory in common with Charles Robin, another investigator who was also loved by the young. Among the beginners of that period who have since made their mark it will suffice to mention our friend Laboulbène, professor in the faculty of medicine, who has recently been snatched from us; Rosenthal, of Vienna, Westphal, of Berlin, Czermak, and others whose names I no longer remember. The vivacity and personal force of Brown-Séquard, together with the simplicity, the innocent sincerity, and the generosity of his character were particularly attractive to young men; but he did not have the same influence upon men of age and authority, who during that period of social constraint, looked upon all innovations with a suspicion fortunately unknown to the present generation.

The method of Brown-Séquard also excited some distrust among those scientists who demand a didactic rigor for all demonstrations. He proceeded rather by intuitions, based upon the execution of incomplete experiments, which appeared still more unsatisfactory because of the extreme complexity of physiological problems. Hence arose many difficulties and doubts, which prevented for a long time the reputation of our future colleague from obtaining that extent and solid foundation which it has since acquired.

At this time he was engaged in researches upon the suprarenal capsules and particularly upon the spinal cord which contradicted the accepted views. These gave him a certain notoriety among neurologists. I will again refer to them later.

Nevertheless, in 1856, the Academy of Sciences awarded him a prize. The fees of the pupils in his laboratory provided him with some resources, and the assistance of Rayer gave him some patients. As his scientific reputation began to be reestablished, the nature of his work gave him authority as a practitioner in the domain of nervous diseases, that field so pregnant with doubts and with desperate hopes. His practice began to assure him the advantages of a professional career. It is well known that men esteem but little those scientific discoveries that can not be turned to profit.

The researches of our colleague upon epilepsy, its etiology and treatment, were especially celebrated. Always active, and always scattering his forces, he took up the most diverse projects. He went to London, Edinburgh, Glasgow, and Dublin to exhibit his discoveries. His authority was at this period greater, perhaps, in England than in France; he was therefore divided between the two countries.

In 1888 he undertook at Paris the publication of the *Journal de Physiologie de l'homme et des animaux*, filled with his own contributions during eight years.

In the month of May, in the same year, he was called to the Royal College of Surgeons of England, and delivered there six lectures in which he summarized his work on the nervous centers and gave his ideas as to the relations between the experimental researches and the therapeutics of the nervous system. These lectures were published in 1860 in Philadelphia; that is to say, in the third of the intellectual centers between which Brown-Séquard continually vibrated.

His experiments on epilepsy, its experimental production, and hereditary transmission, had especially struck the world of medicine and established the reputation of Brown as a neuro-pathologist. Therefore when there was founded in London a national hospital for epileptics and paralytics, Brown was appointed, in 1859, its physician, a position which he held for only a few years. It was there that he finally assumed the character of the chief of a school, and students hastened to attend his instruction. No salary was attached to this position of physician to the hospital, but there were compensations both in the way of honors and of money. In 1861 Brown was elected a member of the Royal Society of London. At the same time he became, in England, a consulting physician whose advice was very much sought, and was in the way to make his fortune. His reputation extended at the same time in France, in England, and the United States, everywhere assured because of his devotion, his activity, and his love for science.

He indeed preferred science for herself alone rather than for any profit that could be gained by her aid. His patients wearied him and his restless nature prevented him from remaining for a long time in the same place or in the same position. As he became more confident of the value of his discoveries, he became more firmly resolved to devote himself to a purely scientific career as soon as he could obtain the necessary means of existence. This confidence had its base in his complete and absolute respect for truth, in his slight regard for personal considerations, and especially in his lack of pretensions to infallibility, a too frequent weakness of some of the most celebrated geniuses.

In 1863 we find him again at Boston, professor of the pathology of the nervous system in Harvard University. It was his wife, a native of Boston, who had persuaded him to this change. His name and teaching had become popular in America. Happy, surrounded by friends, sustained by the influence of Agassiz, who was then all powerful in the American universities, Brown-Séquard seemed to have at last become settled in his life and in his career. Alas! it was then, as often happens in our lives, that misfortune struck him a second blow in his dearest affections and disturbed his life and his thought—his wife died in 1867.

When he lost his mother, seized with a sort of irresistible impulse, he quitted all and fled from Paris to Mauritius, seeking in an irreflective physical agitation, if not consolation, at least distraction from the domestic grief which overwhelmed him. Twenty years after, the death of his wife, whom he had married in 1853, plunged him again into a similarly disturbed condition. He soon quitted the place where his grief had prostrated him, and in 1867 returned to France, resuming there the source of a career that had been interrupted for nine years. Thus his life again recommenced, like a series of equal periodic cycles, in which he continually repeated his triple part of experimenter, journalist, and professor.

As an experimenter he occupied himself with researches ceaselessly begun, laid aside, then taken up again and thoroughly carried out, upon the physiology and pathology of the nervous system.

As a journalist he continued his Journal de Physiologie, abandoned in 1864 for the Archives de Physiologie, published in collaboration with Charcot and Vulpian. Scientific journalism always had for him a particular attraction, in spite of the fatigues and disappointments of the profession. He loved to write according to his own fancy as well as to combine ingenious experiments. He stimulated his collaborators and showed them original work to be done, applauding every novelty, attentive to every mark of talent in young people. He worked much and made others about him work.

As professor he also made his way and became established, thanks to his personal popularity and to the influence of Agassiz and of Rayer, now more powerful than ever as physician to the Emperor, and likewise supported by letters from Agassiz, who had great influence with Napoleon III.

Rayer had made a breach in the long-established routine of the faculty and had undertaken a reform which failed for reasons it is unnecessary to recall here. He profited by his transitory authority to establish, for the benefit of Brown-Séquard, a provisonal course of experimental physiology in the Faculty of Medicine of Paris. Nothing more could be done on the staff, as Brown was not a French citizen. He thus reappeared as a professor where he had been a student in his youth. Claude Bernard, Vulpian, and Brown had climbed up side by side, constantly increasing in reputation and discoveries, the ladder of superior instruction by which we are elevated, little by little, to the first rank, by force of merit and the opinion of our peers.

Brown-Séquard was not made for a didactic lecturer, nor was he likely to carry away his auditors by bursts of borrowed eloquence. But he excelled in displaying his own discoveries with a sincerity that was not wanting in finesse. His researches on the hereditary transmission of nervous lesions attracted the attention of both physicians and naturalists. They were also in close relation with the theories of Lamarck and Darwin on the gradual modification of organisms transformed both by natural selection and the artificial conditions of existence.

But Brown could not bring himself to continue a fixed residence anywhere. During the siege of Paris he was on a journey to the United States, where he gave a series of lectures of which the proceeds were intended for our wounded.

In 1872 there was another change. He married a second time, his bride being an American, Mrs. Carlyle, of Cincinnati, by whom he had a daughter, now the wife of a physician in Dublin. He gave up his provisional chair in Paris at the moment when measures had been taken to naturalize him, so that it could be made permanent, and established himself at New York as a consulting physician. His marriages were always one of the causes of the perpetual oscillations which prevented him from taking root anywhere. He hastened, as was his invariable method, to immediately found a medical journal, The Archives of Scientific and Practical Medicine and Surgery. But few numbers of this journal were published. It contained Brown's first paper upon inhibition and dynamogeny.

This new period of his life was not a happy one. Disturbed by domestic troubles, finding nowhere about him the quiet necessary for his scientific pursuits, tormented by a perpetual need for money which he could not succeed in controlling, his tired faculties no longer sufficing for the simultaneous efforts required for the enforced quiet of scientific reflection and the struggle for material resources, Brown-Séquard now passed some of the most painful years of his life.

On February 12, 1873, in a private letter to a friend, he wrote: "You are young, and you have a numerous family; you have, as a compensation for your exile, the constant assurance of sincere affection. But I, who am growing old with frightful rapidity, have near me only people destitute of any tender feeling. Alas! what will become of me?" "Your departure," he again said, "is the greatest misfortune that has happened to me for a long time. Not only were you a consolation to me by your sincere attachment, you were also a living reminder of the Society of Biology and of my Parisian friends. I can not endure the idea of living here for the rest of my life. I am very unhappy. In the future I intend," he adds, not without a certain artlessness, "to pass four or five weeks in England, three or four months in Paris, and the winter here. I can make a living."

He succeeded in doing this by means of medical consultations. The publication of the journal had led to some losses of money; his lectures brought but little profit. But nervous disorders abounded; in this respect he seemed not to want for resources. "I arrived from Boston to-day (April 20). I have never seen anything like the scenes that occurred yesterday. From 7 o'clock in the morning to 8 o'clock in the evening, when I refused to see any more sick, there was an uninterrupted flow of very patient patients. The last which I saw had been waiting for their turn for five or six hours."

At this time, too, the scientific career of Brown-Séquard appeared to be settled by a definite appointment in America. I refer to a chair of physiology, provided with a vast laboratory and forming part of a great scientific establishment that Agassiz had organized with the aid of a generous patron. The matter should be reported in detail, as it is characteristic of the state of science in the United States.

"You know about Agassiz Island (on the north side of Long Island)," writes Brown to a friend. "It is about as large as the various public parks of London put together; it is very fertile, and is worth, together with the houses that have been built upon it, $100,000. Mr. Anderson, who gave this island to Agassiz, has just authorized him to expend upon it the whole of a capital of $50,000. Agassiz has asked me the direct question: "What will you take per year to carry on the chair of experimental physiology that I propose to found? Include in this all your expenses, for I wish you to give up the practice of medicine." This was even beyond the dreams of Brown-Séquard, and to crown it he adds: "Agassiz is soon going to have thousands of rabbits, guinea pigs, birds, pigs, cats, dogs, and living cold-blooded animals, all of which he will put at the disposal of experimenters. Why am I not again 30 years old!"

But this ideal dream of the physiologist was not to be realized. Agassiz fell sick, and the propositions that he had made to Brown came to nothing. Institutions that depend on the good will of a single person are subject to the same vicissitudes as his life or his mental condition. Those only rest on a solid foundation that have the support of the State, or, at least, that of a great organization controlling unincumbered capital. We have been informed by several European scientists who have settled in America that the regular salaries are small when we take into account the increased cost of living, and the situations are not always permanent, as in old Europe. If donors are easily found to encourage a scientific project, continual support is more rare and often dependent upon the good will of someone, or upon the legislative assemblies, which regulate and change it every year.

In the month of July, 1873, Brown-Séquard was again in Europe, at Brighton, sick, exhausted both by work and by domestic troubles. "I am in the depths of despair; life is odious to me. It is possible that I will never return to America." In October, however, he was again in New York, always a prey to the most sinister foreboding. "I have a constant headache. I think that I am fatally affected." Annoyances of all kinds and money embarrassments increased; his patients did not pay him, and he adds: "They owe me nearly $4,700; I would be bankrupt if an illness should keep me for a month without making anything." His impressionable nature was still more disturbed by his domestic troubles than by his pecuniary embarrassments. "Despair and uncertainty; these are my lot. What would I not give to have you with me. I have so much need of your sympathy and assistance. I can rely no longer on my own health. I fear that I may die suddenly, or fall sick, good for nothing—I am afraid I have a serious cerebral affection. If you have more confidence than I in my health, come to me as soon as possible. As soon as I have no longer any depressing influence near me everything becomes easy. My wife is always very sick; as for myself, I am exhausted." But his generous feelings awaken at the touch of science. "The fact is decisive," he answers a correspondent, who had written him concerning an observation, "it belongs to you; pull the string and you will then pass to another."

In 1874 he lost his second wife, whose conduct had been a source of perpetual torment to him. But he was still disturbed concerning the career of his son. It was at this time that he refused a chair in the University of Glasgow, because of the climate. He repaired to New York, to Chester, to Paris, and in 1875 again returned to New York, always involved in financial difficulties. "I have the means for living just nine months, after which there is absolutely nothing. I must once for all put myself in a position to earn something for my old age, which is rapidly coming on."

The years 1874 and 1875 were thus passed in agitations of all kinds—illness, melancholy, and lamentations—without his being able to decide what to do. He hesitated between Glasgow, Geneva, Paris, and New York. "To choose is very perplexing; there are difficulties everywhere." In the midst of all this he gave lectures on amaurosis and hemianæsthesia; a scientific discussion with Charcot in the Society of Biology excited him greatly. Another trait of character may be mentioned: In 1876 he visited in Paris, as a consulting physician, Dom Pedro, whose affable and open countenance we all remember. Yet Brown-Séquard did not feel entirely satisfied. He saw that sovereigns do not like to be treated on terms of equality; one can always feel the claw under the velvet foot of the leopard.

In 1877 he married a third time, espousing the widow of Doherty, the painter. This wife died in 1894, a few months before him. It was at the time of this marriage that he accepted for a while a chair of physiology in the University of Geneva, but circumstances prevented him from ever occupying it. He had, however, reached the end of his life of wandering and agitation and was about to find among us, in a purely scientific situation of the very first rank, a rest for his declining years, surrounded by honors to which his long career entitled him. He had always been dominated by an ardent zeal for intellectual matters, and he had not hesitated to sacrifice to them the advantages, even though well earned, which belong to a purely professional career.

Brown-Séquard was in New York, in 1878, when he heard of the death of Claude Bernard, who was snatched away after a few weeks' illness by an affection of the kidneys. Brown immediately proceeded to Paris to apply for the position. No chair could suit better this original mind than that which had been occupied by Magendie and Claude Bernard, nor could any teaching be better adapted to him than that in the College of France, a teaching essentially personal and in which each teacher gives out his own ideas and exhibits his own work at the very moment he has completed it, whether in his study or in his laboratory, without any care for a didactic course, following no set programme, not subject to the fatigue of examinations which are at once the evidence of a course and the proof of capacity of candidates for diplomas. This way of considering teaching as a personal matter suited perfectly the vivacious mind of Brown-Séquard, characterized by good qualities and by imperfections, but, above all, original and inventive. He was, therefore, warmly welcomed by the assembly of professors of the college and by the section of the academy, by whom he was presented to the minister. But he had first to go through the formalities of naturalization, which was indispensable to a titular professor.

So Brown-Séquard finally settled in France, and never again recrossed that ocean which he had traversed so many times. He found among us that regular support that was necessary for the carrying on of his work. He ceased to be distracted between the struggle for existence, which must be the care of every man, and the necessity for searching for the truth, which was his individual predilection. Hitherto he had oscillated between the two without being able to resolve to live with such singleness of purpose as would have freed him both from perplexities and weakness in his business affairs and in his scientific work. He henceforth, for sixteen years, lived happily and tranquilly, at least as much so as his ever-active nature would permit.

His activity did not, indeed, decrease.

As early as 1875, at the time when he was making his researches upon inhibition, he touched upon a new subject which he was destined to develop more as the time went on; this was the subject of internal secretions and their physiological significance. In 1881 the Academy awarded him the Lacaze prize; in 1885 the great biennial prize. In 1886 he was elected a member of the Academy of Sciences in the section of medicine. He succeeded Vulpian as he had succeeded Claude Bernard in the College of France. Both had been for a quarter of a century his colleagues in the Society of Biology. They had been presidents of that society. Brown-Séquard also became one in his turn, in the place of Paul Bert, who was younger, but who yet died before him.

He there trained pupils who have since made their mark, and he had for his successor our colleague, d'Arsonval, who served his apprenticeship at the College of France under Claude Bernard and Brown-Séquard, and who took, in his turn, a special flight of his own, giving to his teaching an originality no less striking. So it is that in life we are called to replace successively the friends of our youth and more mature age. We may be counted happy if, during the long course of our existence, our affections have not been chilled or blasted by rivalries, or even by divergencies, at first inappreciable, which gradually separate characters and interests.

In 1894 Brown-Séquard lost his third companion, to whom he had been tenderly attached for eighteen years. Although time had calmed the expression of his feelings, formerly so violent, still it had not chilled his heart. This last stroke was too much for him—he could not bear it. "I can work no more," he said, "all is finished." He returned from Nice to Paris in March, and expired on the 1st of April. At the International Congress at Rome, which was in session at that time, our colleague, Bouchard, with tears in his eyes, read to the section of physiology the dispatch announcing the death of the illustrious scientist.

The entire assembly rose, animated by feelings of respect and sorrow. It sent a telegram of condolence to the Academy of Sciences at Paris—a last homage to the life that was wholly devoted to disinterested research for truth.

The scientific work of Brown-Séquard is considerable in amount and extends to nearly all branches of physiology, these being traversed in turn by this indefatigable explorer.

This work bears the stamp of the personality of the author. It is of an intuitive character, governed by his imagination, quick to perceive the original side of new problems and to attack old problems in an unexpected way. But he did not stick long to any point; he was not one of those who study for a long time with minute attention a particular fact under all conditions until they have a complete knowledge of it. Constantly drawn in divers directions by an inexhaustible curiosity, he had no time to analyze in an extended and rigorous manner the facts he had just discovered. He was in too much of a hurry to get on and had to return to his work again and again and repeat his imperfectly finished studies and demonstrations, for, though he often changed the object of his researches, they were always present in his mind, and he was always seeking to carry them further, never hesitating to acknowledge former errors. This is a phenomenon that has often been noted in the history of science; there is a certain opposition, or, rather, contrast, often seen between the inventive genius who discovers new facts and the precise mind that gives to them the final sanction of exact demonstration. These two kinds of minds are equally necessary and supplement each other reciprocally, without there being, however, any exact line of demarcation between the scientists who possess them. Thus Brown-Séquard, who may be said to be an inventor rather than a demonstrator, once gave at London a lecture (called the Croonian lecture) on the life of the muscles, a lecture cited by John Stuart Mills in his Treatise on Logic as a perfect example of the employment of the four scientific methods.

The labors of Brown-Séquard were directed especially and principally to the elucidation of the necessarily related subjects, the physiology and pathology of the nervous system. During the latter years of his life he added to it a new investigation, equally important, which has opened surprising vistas in medicine—that of internal secretions and their normal office in the healthy human organism, as well as their therapeutic effect upon the organism when diseased.

In the early part of his career, in 1846, he began the study of the spinal cord as the transmitting agent of sensory impressions and motor impulses. He attacked a problem which seemed at that time already solved by the discovery of two kinds of nerve roots taking origin in the spinal cord—the motor roots and the sensory roots. Charles Bell had also extended that distinction to the columns of the cord itself.

The sensory transmission was thought to take place exclusively by the posterior columns, motor transmission by the anterior columns.

This was a very simple and clear doctrine, that appeared to be well established. But in the sciences, especially in those that relate to life, well-defined limitations of this kind are not often found. Brown-Séquard reopened the whole question by his experiments, especially by showing that the transmission of sensory impressions may take place through the gray matter of the cord quite as well as or better than by the posterior column.

At the same time he investigated another idea that had been casually referred to by the brothers Weber—that of inhibition; to this Brown-Séquard returned again and again during thirty years, giving to it immense developments.

The statements of Brown-Séquard were at first received with some distrust, as often happens with those who oppose generally accepted ideas and dominant schools. The official professors of the universities often have their course of instruction fixed and do not like to have the trouble of changing their teaching. Brown finally triumphed, for he pursued his experiments without relaxation, giving them increasing variety and attraction of form. He found that a transverse section of one-half of the cord caused a paralysis of movement on the same side and a paralysis of sensation on the opposite side in regions which receive their nerves from the part of the cord situated above the section. This is what Brown calls a unilateral paralysis. The experimental fact corresponded with various pathological observations made on man and was of use in diagnosing certain lesions of the spinal cord.

This was not all. The reflex power of the cord, almost abrogated at the moment it is separated from the brain, afterwards gradually increases and the section of the posterior columns is followed by hyperæsthesia. In a report read on the 21st of July, 1885, to the Society of Biology, Broca confirmed the exactitude of these experiments, causing a profound revolution in the doctrine of Bell. The discussion continued, none the less heated and active, from 1850 to 1860, without, however, causing Brown, whoever might contradict him, to have resort to those personalities which too often envenom scientific discussions.

A similar question of this sort, yet more complex, separated Brown-Séquard and Charcot in 1874. This was that of the central localization of functions. The paradoxical mind of Brown Séquard was always ready to raise objections to accepted theories. He gave three lectures to the Royal College of Physicians in London to show that there is no relation between a given cerebral lesion and a concomitant paralysis. The question is indeed a complex one, the simple relations which seem so evident a priori being often contradicted by certain secondary effects of a reflex nature, in which intervene some inhibitory symptoms. A local lesion of the cord or brain may thus cause congestions and hemorrhages in distant organs, or, indeed, œdemas and anæmias; it may even disturb or increase the nutrition of those organs; suspend or exaggerate their secretions. These effects may also be produced either on the opposite side from the injured or irritated nerve or on the same side. Conversely, the lesion or irritation of a principal nerve may produce, either at once or after a considerable time, disorders in the encephalic centers. For example, a section of the sciatic nerve increases the irritability of one-half of the nervous system and decreases that of the other half. In this kind of phenomena it may be that the same symptom may result from a lesion of different organs. And, inversely, the real efficient cause, the pathological primum movens can not be ascertained without a delicate and complete analysis of the phenomena. It may be remarked here that the excitability of the sensory or motor nerves that serve as intermediaries for such effects is independent of their special aptitude for the conduction of sensory impressions or motor impulses.

The assembling and interpretation of these phenomena constitute a special branch of physiology developed by Brown-Séquard, and comprised under the names dynamogeny and inhibition. It is an entirely new doctrine, which he opposed to that of cerebral localization. It concerns not only physiology but psychology itself; that is to say, the domain of conduct and intelligence which has its seat in the brain. These are indeed verities of fact independent of any metaphysical theory. Yet, we hasten to add, the conclusions of Brown-Séquard were too absolute. If the facts that he cited did not seem doubtful, he at least exaggerated them by a too wide generalization. He had, however, none the less, the merit of having stated this problem and shown its full extent.

There are few phenomena in which inhibition exerts a more striking influence than in those which result from the action of the vaso-motor nerves. As early as 1851 Claude Bernard had observed the local rises of temperature and increased activity of the circulation that follows a section of the cervical sympathetic nerve. Conversely, Brown discovered that a stimulation of that nerve contracts the same vessels that its section dilates and reduces the temperature of that region which shows a rise when the nerve is cut. By an analogous correlation, if we plunge one hand in water, a thermometer placed in the other hand shows a decrease in temperature.

The development of these ideas may be carried still further, and thus Brown was led to the most remarkable discoveries, for instance, to the experimental production of epilepsy and the hereditary transmissions of lesions by whose aid he was able to produce that malady. His experiments went back, indeed, to 1852–53. They were the immediate result of his investigations upon inhibition, and he carried them on for a quarter of a century. He operated preferably on guinea pigs, animals possessed of considerable vitality and easily propagated. He was therefore always surrounded at his various residences by a collection of these little animals, and was always ready to show to visiting scientists experiments confirming his assertions.

The discoveries I have just sketched all relate to the study of the nervous system. If they do not form a single, methodical whole, they at least show an evident dependence and connection with each other. But Brown-Séquard also attacked other problems, some of which have contributed in no small degree to popularize his reputation. I will not speak here of his experiments upon asphyxia, upon red and dark blood, upon the exciting effect of carbonic acid, and the injurious effect of expired air, distinct from those of carbonic acid, etc. These observations were isolated, or nearly so. But we would leave an important gap in the biography of our friend if we did not give some space to his work and ideas concerning internal secretions.

Among the multiple glandular organs which are found in the human economy, the greater part produce liquids which can flow out through visible channels. The function of the glands is made evident by this means, and that of their secretions is also manifest, at least in a general way. Still, there are some whose use and even existence have remained obscure up to a recent period. Such are the spleen, the suprarenal capsules, the thyroid body, and others that might be mentioned. In 1856 Brown-Séquard took up the study of these functions. He began with the suprarenal capsules, incited to work in this direction by the existence of certain diseases of origin unexplained, except, indeed, that they coexisted with a lesion of the suprarenal capsules. Brown discovered that the extirpation of these glands in an animal was always followed by the death of the animal. This he attributed to the existence of some internal secretion of these organs, a secretion continually discharged into the blood and necessary for life. But he went no further at this time, and did not take the subject up again until twenty years later, in 1889.

This time he tried another gland and examined the physiological action of the testicular fluids, being led by divers reasons to suppose that those fluids contained certain substances which they also discharged into the blood and which tended to exalt the power of the nervous system and to keep up the vital energies. He did not hesitate to extract these fluids from the organs of animals and to make upon himself, by means of hypodermic injections, certain trials of them which appeared decisive. He concluded that he had discovered a new therapeutic method. The subject required delicate manipulation, not only because of the extraordinary precautions required for this kind of inoculations, but of charlatanism, always ready to possess itself of new curative procedures. Brown-Séquard did not cease to protest against the abuse by which his name was made to cover industrial enterprises. But he persisted in the idea and it developed with increasing importance, until it now constitutes an entire new method, designated under the name of opotherapy, or treatment by organic extracts. Extracts from the pancreas, the liver, the suprarenal capsules, the spinal cord, the ovary, the prostate, the testicle, the thyroid gland, have thus been successively used in therapeutics with varying degrees of success.

The study of the thyroid extract especially has led scientists to the most unmistakable results.

This subject has not failed to extend itself still further. In fact, the preparation and effects of these various extracts have come to be confounded with serotherapy or the treatment by serums, modified for the purpose of combating diphtheria and various other diseases. The old inoculation of the virus of smallpox and the vaccination of Jenner have been brought under the same category of ideas. But it is beyond the limits of the present notice to try to state, even in a summary manner, the developments, every day more extensive, of the new doctrines and therapeutic methods. Under their influence the theory of germs is itself undergoing profound modifications, which tend to change the views which were at first held. Not only are the effects produced by microbes upon living organisms referred more and more to the domain of chemistry, and considered as independent of life, but the real agents that cause these phenomena are no longer supposed to be the microbes themselves. According to the new doctrine it is not the microbe that acts by virtue of its own life, carried on either with or without the assistance of air, in producing the phenomena of disease or of fermentation; but, as I formerly thought, if I may be permitted to cite myself, the real agents of all these phenomena are chemical agents, properly so-called, secreted by the microbes, yet distinct from them. These are immediate definite principles belonging to the class of the alkalis or the amides, that act either as toxines or antitoxines, according to circumstances.

In this way there tends to be formed an entirely new system of physiology and of practical treatment of disease, a system which recalls in some respects, and in certain of its methods, the primitive conceptions and even the superstitions of the early days of medicine. We certainly do not wish to fetter ourselves with the formulas of such a system any more than with those of the old ideas concerning the spiritual cause of disease and the vitality of miasms, or with those of the recent theories of the necessary and universal influence of microbes in pathology. Modern science does not become petrified in any dogmatism; but its incessant evolution is regulated by the very succession of discoveries accomplished according to its methods. Now, it is certain that the study of the internal function of glandular cells and that of the secretions of microbes has become to-day the point of departure for an entirely new set of therapeutic procedures; unknown ways have been opened by these discoveries for physiology and the medical sciences. To Brown-Séquard will be given the glory of having been one of the conquerors in this new domain.

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